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An Experiment With Space Station Pricing Policies

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Abstract

In the late 1990s the National Aeronautics and Space Administration (NASA) plans to operate an earth orbiting space station. For decades into the future the station is expected to play a dominant role in U.S. space research and in the commercialization of space. If the expectations are correct, then the station will be a complex of potentially valuable resources and services. Much sentiment exists within the government that the allocation of those resources should be based on some sort of market-oriented policy (a more "business-like" approach). This paper is part of a larger project that is intended to ascertain what that policy might be.

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INTRODUCTION

In the late 1990s the National Aeronautics and Space Administration (NASA) plans to operate an earth orbiting space station. For decades into the future the station is expected to play a dominant role in U.S. space research and in the commercialization of space. If the expectations are correct, then the station will be a complex of potentially valuable resources and services. Much sentiment exists within the government that the allocation of those resources should be based on some sort of market-oriented policy (a more "business-like" approach). This paper is part of a larger project that is intended to ascertain what that policy might be.

Laboratory experimental methods have played several roles in the larger project. For example, the design of an experiment requires a complete specification of the finest details of the policy and of the economic environment in which the policy will operate. The detailed focus demanded by the small-scale creation of the policies and environment raises questions that might never be asked until the actual environment is faced and when it is too late to generate thoughtful answers. The very act of creating an experiment means that issues of timing, forms for gathering and reporting information, methods of resolving conflicts and uncertainties, and other institutional details that give a policy life are specified in operational (as opposed to abstract) terms. This role of experimental methods as a heuristic is well recognized by experimentalists (Plott 1987).

This report deals with an additional feature of experiments. The experiments provide a source of experience and data about how various policies might work. An experimental environment has been created that contains features and events that are believed will be present in the field space station environment. Implementation of policies in such a "testbed" environment provides a first-stage evaluation of the policies' performance properties. Presumably the first-stage testing will be followed by more advanced stages that incorporate more complicated environments and test any weaknesses the policies seem to exhibit. Follow-up studies should focus on variables that researchers feel might change the results. Laboratory research should be followed by simple field tests. Thus, the purpose of the study is to provide a first-stage evaluation of policies. In addition, the purpose is not only to answer questions but also to stimulate questions which might be answered by second-stage and third-stage research.

We recognize that this use of experiments might not conform to everyone's beliefs about the proper role of experimental methodology in economics. These experiments are complicated relative to other experiments found in the literature. We suspect, however, that the approach adopted here is not significantly different from the techniques that have evolved in engineering, medicine and other applied fields in which the basic principles governing phenomena cannot be seen through the complexity. We are aware of no alternative methods for testing policies short of the actual field application. Cost and politics seem to preclude any sort of field experiments in the case of a space station. Almost certainly no radical departure from historic policies will be implemented or even tried in the absence of data that suggest that the policy would work smoothly in a complex environment. We have been careful to contain the discussion and conclusions within this special-purpose experimental methodology.

As will be outlined in the section that follows, this study is a comparison of four policies. For the most part the questions posed are very broad and reflect an attempt to decompose the even broader questions asked by those responsible for policy implementation: "will the policy work?"

and "how will the policy work?" The environment is complex. The economics is complex. The policies are complex. The principles and arguments used by economists appear to be abstract. A *demonstration* seems to be an answer to many different types of questions that such complexity fosters. The list below is an attempt to isolate some of them.

a. Does the policy lead to allocation decisions in the complex environment, or does it simply grind to a halt? The weight of confusion, conflict, paperwork, etc. might lead to no decisions at all or possibly to so few decisions that the policy is impractical.

b. Is the policy complete in the sense that important contingencies are anticipated? Because the agents are human with their own perceptions, search strategies, etc., the strategy spaces might be much richer than imagined by the designers. Does the policy deal smoothly with situations that were not anticipated by the policy designers?

c. Is the quantitative performance of the policies that which is predicted by such theory that exists? Are deviations from predictions of theories understandable in terms of those theories? Since the models are simplifications of the actual environment, errors due to simplification must be separated from more basic errors involving the principles that are at the foundation of the policy. If the theory seems substantially correct, then research can proceed on the assumption that the theory will be reliable in more complex environments and that the understanding or intuition of possible policy behavior gained from theory is reliable.

d. What is the comparative performance (efficiency) of the policies? Which policy is "best?" Are the conclusions about relative efficiency sensitive to the particular environment? What type of performance measures, other than efficiency, are appropriate for answering the question? How would the policy perform (better or worse) if it is changed from the way it was implemented in the experiment?

Our experiments have been designed to directly answer these broad questions. In addition, the experiments are to be used as a demonstration to inform those individuals who will implement allocation policies about the possible consequences of various policies. This purpose of our experiments was to provide a "nontechnical" presentation to those who must explain the details of a policy to a wide constituency. The only way we can provide the insight required by these individuals, so that they will have confidence in explaining (and understanding) the policies and the principles that might lead to their effects, is to participate in the policies. We will report on this aspect of our experiment below (section five).

OVERVIEW

The study is divided into nine major sections. The next section describes the economic environment. Section four lists the policies to be studied. Section five specifies some models based on the behavioral principles that tend to guide economic thinking about the policies. Section six is a brief outline of the experimental design. Section seven is a discussion of the results that bear on policy evaluation. Section eight is a discussion of the results as they are related to the accuracy of the models in predicting the data generated by the experiments. The final section contains remarks that are reflections on the study.

THE ENVIRONMENT (EXPERIMENTAL TESTBED)[1]

The economic environment reflects judgements about the types of relationships that will exist in the actual environment as seen by economists and engineers. Frequently these judgements reflect opinions held by one or more decision maker that some aspect will be present in the actual environment and will be a challenge to a policy. These judgements are reflected in the nature of tradeoffs and uncertainties built into the experimental environment. A desire to be able to compute certain interesting magnitudes (e.g., competitive equilibria and efficient allocations) was also a consideration in the choice of environmental parameters. The limitations imposed by existing experimental technology were also important. Other opinions about facts, theories, or the capacity

1. For a detailed description of the environment, parameters, and timing for the experiments of this paper, see Porter (1987).

of experimental technology could have lead to a different environment.

The economic environment designed for the experiments consists of a set of contingent space station resources to be allocated to a group of seven agents. Each of the agents must commit some capital to *design* and *develop* a project (this is defined as a payload). Operation of the payload involved the use of space station resources to produce some output. We shall now discuss each of the elements of this environment in turn.

Space Station Resources to be Allocated

The supply side of the environment consisted of three resources to be supplied by the station:

1. Launch of payloads to the station. This resource is called *mass* and the quantity available is M.
2. Electric power supplied to payloads for operations. This resource is called *power* and the quantity available is P.
3. Manpower supplied to payloads for operations. This resource is called *hours* and the quantity available is H.

These resources are subject to supply-side uncertainty. The amount of a resource available will be either rated capacity $\overline{M}$, $\overline{P}$, $\overline{H}$ or something less $\underline{M}$, $\underline{P}$, $\underline{H}$. The parameters governing uncertainty are described by the following notations and conditions:

$$M = \begin{cases} \underline{M} \text{ with probability } \rho_M \\ \overline{M} \text{ with probability } (1-\rho_M) \end{cases}$$

$$P = \begin{cases} \underline{P} \text{ with probability } \rho_p \\ \overline{P} \text{ with probability } (1-\rho_p) \end{cases}$$

$$H = \begin{cases} \underline{H} \text{ with probability } \rho_H \\ \overline{H} \text{ with probability } (1-\rho_H) \end{cases}$$

That is, "failures" of station resources are independent and result in a reduction in available station resource capacities.

We shall consider a simple set of *contingent resources* (contracts) called *priority contracts*. A priority contract describes the order of dispatch of a resource. First priority resources in our environment are those that will be available in all states. Second priority are those that are available only if the station operates at full-rated capacity. We call $M_1 = \underline{M}$ *priority 1 mass* and $M_2 = \bar{M} - \underline{M}$ *priority 2 mass*. Similarly, $P_1 = \underline{P}$ is *priority 1 power*; $P_2 = \bar{P} - \underline{P}$ *priority 2 power*; $H_1 = \underline{H}$ *priority 1 hours*; $H_2 = \bar{H} - \underline{H}$ *priority 2 hours*.

We will assume that the capacities (M, $\underline{M}$, $\bar{P}$, $\underline{P}$, $\bar{H}$, $\bar{H}$) and probabilities (ρ_M, ρ_p, ρ_H) are common knowledge to participants. Furthermore it is assumed that long lead times are needed to expand (or contract capacity) and resource costs are fixed in the short-run.

Time in the experiments was measured in launches so that a *period* consisted of the activities performed between launches. Where necessary the index $t = 1, 2, \cdots$ represent periods in which resources are consumed, a launch takes place, and payload operations using station resources are performed.

Payload Decision Variables

An agent (payload designer) in this environment will be confronted with decisions concerning *payload design, level of operations* (resource use), and *timing* (period of consumption). The notation is developed from the point of view of some fixed decision maker so the indexes of different decision makers can be dropped.

A payload must first be designed and developed which takes both time ($\theta =$ development time – which can be either 1 or 2 periods in the environment) and capital ($C =$ dollar amount). The payload payoff (in dollars) depends on both the level of resource used and the design selected. For the experiment we used quadratic payoff functions given by:

$$B(p, h; a) = \alpha_1 p - \gamma_1 p^2 + a^{\gamma_3} [\alpha_2 h - \gamma_2 h^2] \tag{1}$$

where a is the design variable intended to capture the notion of *automation*, and p , h are the levels of power and hours used by the payload. The α 's and γ 's are parameters that are determined by the general characteristics of the payload (i.e., the type of agent). The *mass* of a payload is given by

$$m = m_0 + m_1 + m_a a + m_d d \tag{2}$$

where m_0 is *initial mass*, m_1 is *design mass*, and m_a is a fixed coefficient of automation mass (in the experiment $m_0 + m_a a$ was called *primary payload mass*). These are all constants that characterize a design. The variables m_d and d will be discussed below.

The *design cost* was given by:

$$c = c_0 + c_a a - [\gamma_3 m_1 - \gamma_4 m_1^2] + c_d d \tag{3}$$

where c_0 is *initial costs* and c_a the fixed coefficient of automation cost. The parameters are generally chosen such that over the domain of feasible choices, design costs, and mass are inversely related. The variables c_d and d will be discussed below.

In addition to automation, a payload could be designed to be more *reliable*. To introduce this notion we will assume that a payload has a probability of an operating mishap that is given by σ. If a payload mishaps, it will have a payoff function given by:

$$\gamma_0 \cdot B(p, h; a) = \hat{B}(p, h; a) \tag{4}$$

where $\gamma_0 \in [0,1]$. A mishap simply scales back the benefits by a constant γ_0.

A mishap can be avoided at a cost. A payload designer in our experiment will be able to counteract a mishap in two ways. First, he/she can design using his/her own input (d) to reduce the probability of a mishap in the following manner:

$$\sigma = (1 + d)^n \tag{5}$$

where $n \in (-\infty, 0)$.

However, d will affect equations (2) and (3) by the factors $m_d d$ and $c_d d$, respectively.

Second, the agent can use station resources to *backup* his/her payload to prevent mishaps by using additional mass (m_b) or hours (h_b) such that

$$0 = \begin{cases} 1 & \text{if } m_b = m^* \quad or \quad \text{if } h_b = h_b^* \\ \gamma_0 & otherwise \end{cases} \tag{6}$$

In other words, mishaps can be avoided by adding backup which comes in either a lump-sum mass or in lump-sum manhours. Thus, the expected value of choosing a design (a, d, m_b, h_b) is given by:

$$(1 + (\gamma_0 - 1)(1 + d)^n)B(p, h; a) - C(a, d, m_1) = \tilde{B}(p, h, m_1; a, d, m_b, h_b). \tag{7}$$

Next, we introduce the condition of an *operating life* of a payload. Specifically, a payload will either have a one- or two-period operating life after which it produces no benefits (payoff). Notice that this implies that a payload with a two-period operating life requires no launch mass in its second period of operation.[2]

To close this system, we imposed "inventory" costs on subjects for the projects they developed and operated through ground cost per period prior to the launch of their payload and in-flight ground cost for each period their payload is on the station.[3]

It is clear from this discussion that our experimental environment is very complex and detailed. As mentioned in the introduction, this complexity was introduced to see how well a policy could resolve uncertainties. In addition, the existence of this complexity was utilized to make those responsible for implementing actual policies to develop better insights about how complexity is handled by the policies. This complexity was not without its costs. First, subjects must be made familiar with all these aspects of the environment. This means that payoffs had to be large so that subjects are sufficiently motivated in their decision making. In addition, ample time

2. As an additional constraint subjects were allowed to operate only one project per period.

3. These costs are *fixed costs* in our model given by: $C_g \theta + C_f o$ where C_g are ground costs per period, C_f are in-flight costs and o is the operating length.

for experience would be needed. Second, pinpoint predictions of theoretical models become difficult as the complexity increases. These aspects of our experiments are discussed later in this paper.

Timing

The process followed the calendar of events contained in Figure 1. Each of these events involved a decision by some agent or by the experimenter. The nature of these decisions will be outlined in the sections that follow. Now only a brief outline will be given.

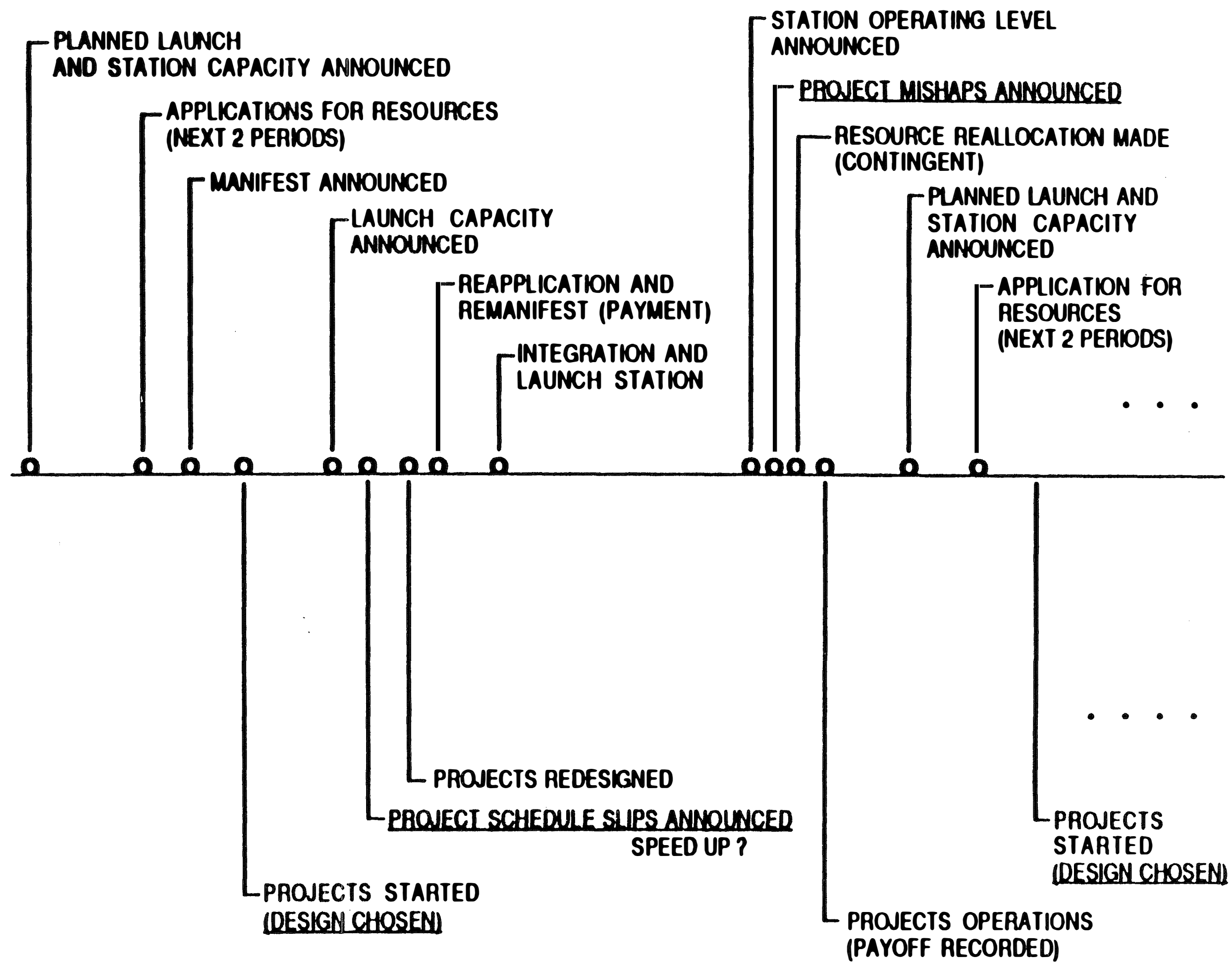
The experiment begins with an announcement by the experimenter about the amount of resources that would be available to agents who would be on the next launch. After this announcement, project managers would submit an application for a launch. Applications were processed and successful applications (a manifest) were announced. Project managers would begin projects. Final assessments of the launch capacity were made by the experimenters and any excess capacity was announced. Project managers learned about progress on their projects (a decision by nature) and decided whether or not to spend resources in order to accelerate completion of their projects. Additional resources were allocated after reapplication and launch took place.

Once projects are launched to the station the operating level of the station was assessed (a move by nature). Project managers also learned about the ability of their projects to operate in space (another nature choice). If the station was operating at less than capacity, decisions were made concerning which projects would receive fewer station resources. After this the projects operated and the cycle began for the next launch.

System Optimum

To find the optimal allocation of resources (mass 1 (m^1), mass 2 (m^2), power 1 (p^2), power 2 (p^2), hour 1 (h^1), hour 2 (h^2)) and payload designs (a,d, and backup) one must solve for expected system profits. The formal problem is:

FIGURE 1
CALENDAR OF EVENTS



$$\max \sum_{j \varepsilon \{M,P,H\}} \rho_j \, \tilde{B}_i(p^1, h^1, m_2^1; a, d, m_b, h_b) +$$

$$(m^1, m^2, p^1, p^2, h^1, h^2, a, d, m_b, h_b)$$

$$\sum_{j \varepsilon \{M,P,H\}} (1-\rho_j) \sum \tilde{B}_i(p^1 + p^2, h^1 + h^2, m^1 + m^2; a, d, m_b, h_b)$$

subject to the capacity constraints where the $\sum$ is over payloads:

$$\sum p_i^1 \leq \underline{P}$$

$$\sum p_i^2 \leq \bar{P} - \underline{P}$$

$$\sum (h^1 + h_b) \leq \underline{H}$$

$$\sum h \leq \bar{H} - \underline{H}$$

$$\sum (m_o + m_1 a + \cdots + m_2^1 + m_b) \leq \underline{M}$$

$$\sum m_2 \leq \bar{M} - \underline{M}$$

Appendix A supplies the set of parameters chosen for our environment. Table 1 supplies the optimal allocation of resources in our environment and associated environment variables. There are four aspects of this table which will be important for the measurements we will make later.

1. At the optimum, subject 7 should *not* consume any station resources. He/she should operate a "ground project."
2. At the optimum, projects should not use backup. The use of station resources to backup projects is a socially *inefficient* form of insurance.
3. The level and mix of resources varies significantly across subjects. This reflects the fact that there will be a variety of station users.

TABLE 1

OPTIMAL PAYLOAD CONFIGURATION

RESOURCE USE

SUBJECT	DESIGN	MASS		POWER		MANHOURS	
		1	2	1	2	1	2
1*	B	9	4	2	2	2	2
2	D	12	3	3	5	1	2
3	A	15	1	1	2	3	5
4*	C	15	5	4	1	2	2
5	E	8	3	1	2	4	1
6	A	15	1	2	3	4	2
7	B	0	0	0	0	0	0
TOTALS		74	17	13	15	16	14

* Two-period operating projects

Number of payload designs per subject:

5 x (3 back-up choices) = 15 possible designs

Probabilities of resource supply:

$\rho_M = .33 \qquad \rho_P = .50 \qquad \rho_H = .33$

Capacities of Resources:

Even Periods		Odd Periods	
$M = 91$	$\underline{M} = 74$	$M = 58$	$\underline{N} = 50$
$P = 28$	$\underline{P} = 13$	$P = 28$	$\underline{P} = 13$
$H = 30$	$\underline{H} = 16$	$H = 30$	$\underline{H} = 16$

4. The level of mass resources varies by period since a two-period operating project requires no mass in the "off" periods. Thus, an optimum requires payloads to synchronize launch time.

POLICIES

The policies developed in this section are based on descriptions of policies being proposed to NASA to price the resources of the station. These policies were developed from the "Operations Task Force Summary Report [OTF]" (1987) and Banks, et al (1989). Thus, the policies we consider are based on a preliminary proposal to NASA.

Policy 1. Cost-based Administered Process (CBAP)

This policy is intended to represent the space shuttle pricing and allocation policy prior to the Challenger disaster. In addition, it is also a description of accounting or cost-based policies; i.e., a simple posted price to be paid for specific resources (e.g., weight, volume) which is calculated on a cost measure (e.g., marginal cost, fully allocated cost, etc.). Since this type of policy does not fully specify how one obtains an allocation, some additions must be made to the process to determine who gets what (e.g., first come first served, committee review).

For purposes of the experiment subjects were designated as priority one, two, or three.[4] This designation of priority according to subjects as opposed to resources reflects the NASA policy of assigning priority to users. At the beginning of a period individuals could make an *application* for resources (mass, power, and manhours) for the next two periods. Applications were filled on a first-come, first-served (random) method based on priority (priority one subjects allocated first, and so on). Figure 2 supplies the general application form used for each policy which reflects the fact that individuals are given priority. In addition, if resources became constrained, they were to be filled on the basis of individual priority.

4. Subjects 3 and 6 were assigned as priority one; subjects 2, 4, and 7 were assigned as priority two; and subjects 1 and 5 were assigned as priority three.

FIGURE 2

Participant ____________
Priority ____________

APPLICATION

Application Number ____________
Project State Number ____________

Launch Preference (Ordered Dates)

First Preference ____________

Second Preference ____________

Number of Periods on Station ____________

Mass:	Priority 1	____________
	Priority 2	____________
Backup:	Priority 1	____________
	Priority 2	____________
Total:	Priority 1	____________
	Priority 2	____________

Consecutive Periods on Station

			1st	2nd	3rd
Power:					
	Operations	Priority 1	____________	____________	____________
		Priority 2	____________	____________	____________
Manhours:					
	Operations	Priority 1	____________	____________	____________
		Priority 2	____________	____________	____________
	Backup	Priority 1	____________	____________	____________
		Priority 2	____________	____________	____________
	Total:	Priority 1	____________	____________	____________
		Priority 2	____________	____________	____________

During a period after the final launch capacity was announced, individuals could reapply for any unused capacity. The only constraint was that subjects had to have the mass available to launch their project or it was taken off the manifest. Finally, there were prices charged for each resource to be paid at the time of manifest. The prices chosen were significantly below the competitive equilibrium prices so that in principle "excess demand" would occur. The prices were posted as follows:

Mass = $0.25

Power = $1.50

Hour = $1.25

In the shuttle environment it is believed that this form of scheduling has contributed to biasing lower-priority payloads towards smaller, easy-to-integrate packages (these are known as get-away-specials [gas cans]) in order to minimize the opportunity cost of delay.

Policy 2. Barter.

This policy is an attempt to capture a process in which resources are divided among identified participants who can use them or trade them for other station resources. This proposal (see OTF Report) assumes that an administrator or administrative committees allocate initial endowment of station resources to users who can barter among themselves.

In the experiment we initially gave participants three envelopes of resources (mass 1, mass 2, power 1, power 2, hour 1, and hour 2) corresponding to the first three periods of operations. Individuals were allowed to barter with any other participants and resource transactions were conducted using slips of paper indicating a unit of a specific resource, priority, and time period. Trades could be made across time, priority, and resources. There were no formal trading rules or market makers. However, since there were only seven station users and all were assembled in the room, the bargaining sessions were frequently in the form of larger sets of people and group discussion. At the beginning of a new period an additional envelope was given to subjects corresponding to two periods in advance. Thus, subjects always had three periods of resources in which to make their utilization plans.

Policy 3. Adaptive User Selection Mechanism (AUSM).

This mechanism was an extension of the proposal found in Banks, et al (1989). This mechanism is a generalization of the English (or ascending-bid) auction. The mechanism is based on the principle that the "item goes to the current highest bidder who pays his bid," with an improvement rule in the bids.

An order in AUSM consists of a vector of resources z_i, a priority class $p \in P$, a time period $t \in T$, and a dollar bid b_i, that is the triple (z_i, p, t, b_i). If $\vec{z}_p^t$ is the capacity of resources of priority p, a time t, then the standing allocation of resources is given by the solution to

$$\max \sum_{i \in C} b_i$$

such that

$$\sum_{i \in C} Z_{ip}^t \leq Z_p^t$$

where C denotes the set of all combinations of orders submitted. The solution to the above gives an allocation which can be changed only if another order

a) fits within the available capacity, or

b) displaces existing orders with lower bids.

Because of the lumpy nature of demands and the importance of packing resources, there may be changes in allocations involving several traders *simultaneously* which can make all better off. In particular, if a large package and bid is part of the current potential allocation, it may be costly for one "small" user to displace it. Several "small" users may be required to displace the bid. In order to avoid these possible allocations, we allowed subjects to coordinate their bids through public off-board bids in which subjects could post a "proposed order" (z_i, p, t, b_i) which could be combined with other individuals. This off-board bidding was intended to signal coalitional bids to other agents.

In the experiment, AUSM was conducted as a computerized bulletin board in which orders and standby orders were submitted by subjects and the provisional allocation updated as a new bid arrived. The order and bid was binding[5]

and, in the case of priority two resources, agents paid their bid whether or not they eventually received the resources. They paid for the right to the resources if the resources existed at the time they were to be used.

Policy 4. Multiple Unit Double Auction (MUDA).

This policy proceeded exactly like the barter policy (envelopes, priority, three time periods, etc.); however, the trading was organized differently. In particular, subjects could *buy and sell* resources for cash on an organized exchange with a bid-ask spread improvement rule using the multiple unit double auction in each market that was open (Plott and Gray, forthcoming in JEBO). A total of eighteen markets were open at any one time. There were three types of resources, two priority classes, and three time periods. Thus, both spot and futures markets were available to subjects to coordinate actions.

MODELS

Several models are available to help organize and interpret the data. The complexity of the environment prevents a complete specification of any of them. Fortunately all of the models yield similar diagnoses about the consequences of various policies. Had the models given contradictory predictions, an experimental design that permitted a more complete specification would have been necessary.

Three models can be applied. A fourth, the most efficient allocation, is not a model. It is a measuring device that indicates the limits that exist under any particular policy. All four are listed

5. However, standby bids could be removed from the queue by the subject.

in Table 2 together with the known prominant features of each.

The core has not been calculated. A complete calculation would rest upon unsupported assumptions about attitudes toward risk. Under MUDA and AUSM an external medium of exchange exists so the most interesting allocation in the core is the most efficient allocation if indeed there is anything else in the core. Under Barter and CBAP the situation is much different. The parameters were not chosen so that double coincidents of wants existed throughout the agents. That is, the gains from exchange sometimes could not be attained through mutually beneficial two-party trades. It was necessary for either source to take a risk or for three or more people to be part of a trade. Under Barter major improvements in efficiency over the status quo would appear to be difficult. Under CBAP the "treat point" is different than under Barter. Priority one agents are greatly advantaged and according to the model this advantage has consequence for all other agents.

The competitive equilibrium has been calculated. It is a natural prediction to make when markets are open as is the case with MUDA. The model would seem to be inapplicable in the other policies. The parameters were constructed such that the equilibrium exists for risk neutral agents. Since futures markets are involved, the only equilibrium explored is the stationary equilibrium. Table 1 gives the equilibrium resource holdings for each agent. Figure 3 contains a graph of the demand and supply for manhours, and associated competitive equilibrium prices for priority 1 and 2 resources.[6]

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6. To determine these prices notice that if B(x) is the benefit/payoff for x then the market clearing prices are determined by finding:

$$\max \rho\, B(x_1) + (1-\rho) + B(x_1 + x_2) - p_1 x_1 - p_2 x_2$$

where ρ is probability of constrained supply and x_1 is a vector of priority one resources and x_2 is a vector of priority two resources and where

$$p_1 = \rho B'(x_1) + (1-\rho)\, B'(x_1 + x_2)$$

$$p_2 = (1-\rho)\, B'(x_1 + x_2)$$

or

$$p_1 = \rho B'(x_1) + p_2$$

and

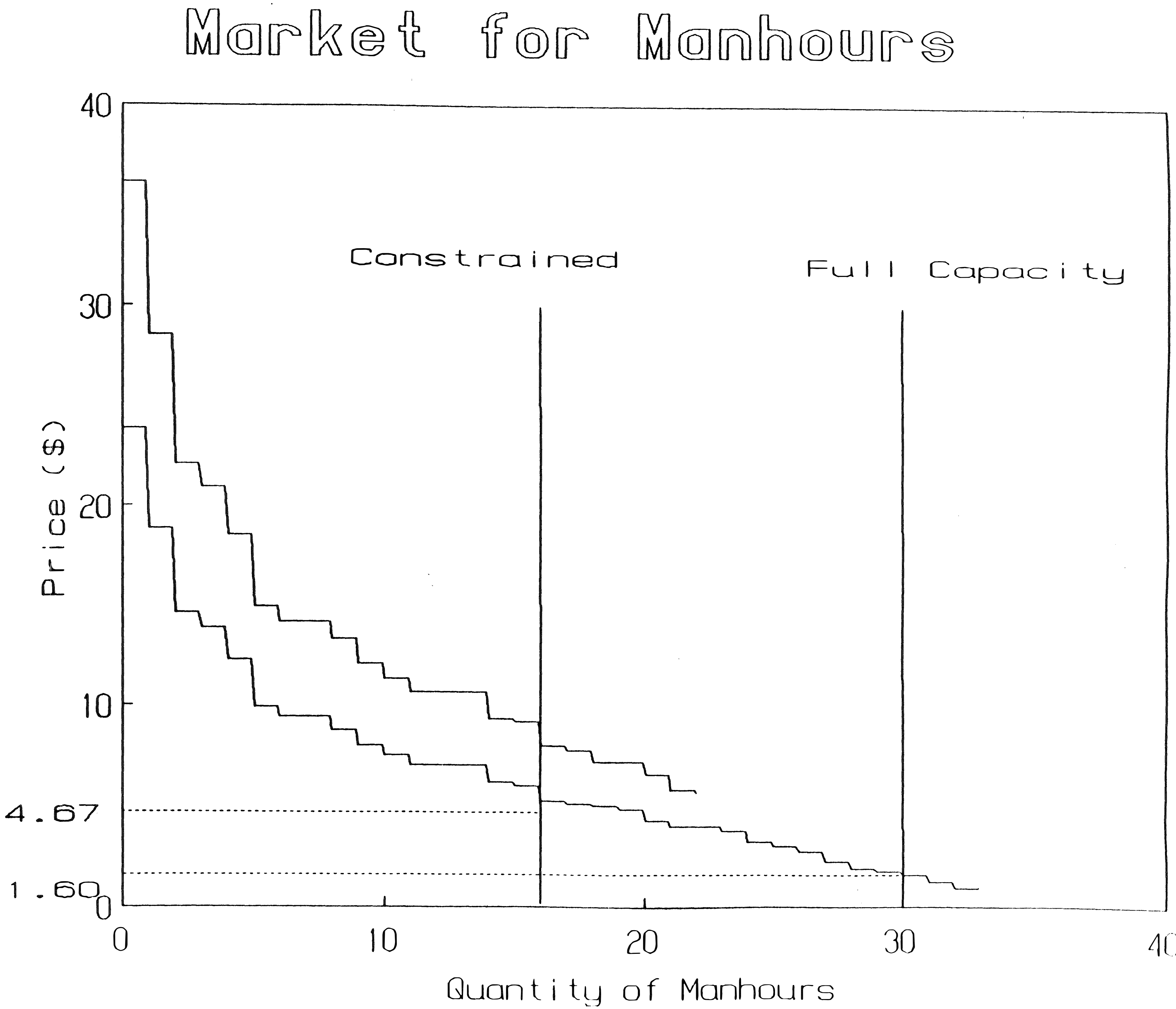
$$x_1 + x_2 = \bar{x}$$

TABLE 2

PREDICTIONS OF POLICY OUTCOMES BY VARIOUS MODELS

	Outside Money		No Exchange Medium	
	MUDA	AUSM	BARTER	CBAP
Most Efficient Allocation	100% Efficiency	100% Efficiency	100% Efficiency	100% Efficiency
CORE	(i) contains most efficient allocation	(i) contains most efficient allocation	(i) efficiency improvement over initial endowment (ii) ground project gets on Station (iii) Large projects do not get "additional resources"	(i) priority one agent choose persona maximums (ii) priority one agents use resources for backup (iii) low priority agents scale–back (low eff.)
Competitve equilibrium price and allocates	(i) prices observable	(i) indirect prices are observable (ii) allocation is the most efficient	(i) no direct prices per resource is observable	(i) no market activity is observable
Noncooperative game	No complete game theoretic model exist	Many exist. The most efficient allocation is a Nash equilibrium. The strong Nash is implementable with off–board		Nash equilibrium implies that Priority 1 agents take all they want. Others scale back. Coordination problems exist.

FIGURE 3



Market for Manhours
Constrained
Full Capacity
Price ($)
Quantity of Manhours
40
30
20
10
4.67
1.60
0
0
10
20
30
40

For the most part the situation is too complicated for any simple application of game theoretic models. The table contains some properties.

EXPERIMENTAL DESIGN

The elements of experimental design are in Table 3. Subjects recruited for the experiments were undergraduates at the California Institute of Technology. The subjects were told that they were going to participate in an experiment that would require their involvement over five days with sessions lasting approximately four hours each day. An introductory one-hour session was given to the subjects during which instructions were read giving a description of the environment and individual payoffs. Subjects were allowed to take home their payoff sheets for a day and could call the experimenter for any clarification of their payoff sheets.[7]

Although only seven subjects were used in the experiment we recruited and trained eight subjects so that one individual could be used as a reserve if a participant could not make it for emergency-type reasons. (Participants were told that if they did not show up for any day of the experiment, they would forfeit their accumulated earnings.) The reserve subject assisted in recording data from the experiment and was paid the average earnings in the experiment. The backup student was never used.

In our third experiment, we used engineers, managers, and consultants from NASA Headquarters (Washington, D.C.). These individuals have the responsibility of developing and implementing station resource allocation policies. This experiment was complicated by two important facts concerning these subjects. First, we were not allowed to pay these individuals for their participation in the experiment due to legal concerns of "double pay." Second, these individuals would be available for *only* one (8-10 hour) day. In order to loosen these constraints and maintain the saliency in individual decision making we supplied each NASA participant with a

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$x_i = \underline{x}$

7. Individuals *did* take advantage of this "study time" to call in their questions and develop their own individual aids to make design decisions.

TABLE 3*

Experiment	Date	Subject Pool	Order in which Policies were Conducted
1	June 12, 1988	Caltech	AUSM, Market, Barter, CBAP
2	September 4, 1988	Caltech	Market, Barter, AUSM, CBAP
3	February 17, 1988	NASA	Market, CBAP, AUSM

* The instructions and payoffs used in this experiment can be found in Appendix C.

technical advisor (a Caltech undergraduate). The technical advisor was familiar with the timing, application process, and potential payload payoffs. All decisions had to be made by the NASA subject. The payoff from the decisions made by the NASA subject during the experiment was to be paid to the Caltech undergraduate technical advisor assigned to the NASA subject. The cover letter sent to each participant inviting him/her to the experiment can be found in Appendix B.

Payoffs from the experiment were established at a high level so as to properly motivate the participants to understand the complex environment they faced (the average payoff for the four-day sessions was $345 or approximately $21.50 an hour).

We conducted three separate experiments in this environment with the subjects participating without changing their payoff opportunities during experiments. Table 3 provides an overview of the experimental design for the experiments we conducted.

RESULTS: POLICY EVALUATION

The results are discussed in four subsections. The first reports the overall efficiency of the policies. The second contains an analysis of the efficiency results in which the sources of inefficiency are explored and the degree to which the relative performance can be understood in terms of traditional economic models is discussed. The third section discusses signals for growth of the station resources (M,P, and H). Each policy generates data that are observable to policy makers. If decisions to expand various dimensions are administrative in nature, certain signals are natural ones to explore for purposes of policy decisions. The section explores the degree to which the signals are correct. The fourth section discusses the accuracy of models that might be applied to capture the prominent features of the processes.

Efficiency

All of the parameters are known to the experimenter. Consequently it is possible to determine the allocation of resources that will maximize the total expected profit of station users.

Since station resources are fixed in supply, all sources of inefficiency exist on the users' side. In models that are continuous approximations of the process, maximized expected profit implies ex ante Pareto optimality in the absence of risk aversion.

The measure of efficiency we use implicitly assumes that the benefits to all users are equally weighted and that total benefit is a linear function of individual benefit. In the absence of specific interpretations or goals, this measure of efficiency seems to provide a good indication of how gains from exchange might have been exhausted by the process. It is important to notice however that the measure does assume that the "social" utility of projects has been scaled to be a dollar metric.

Result 1. The policies ordered from highest to lowest efficiency are market, AUSM, barter, CBAP.

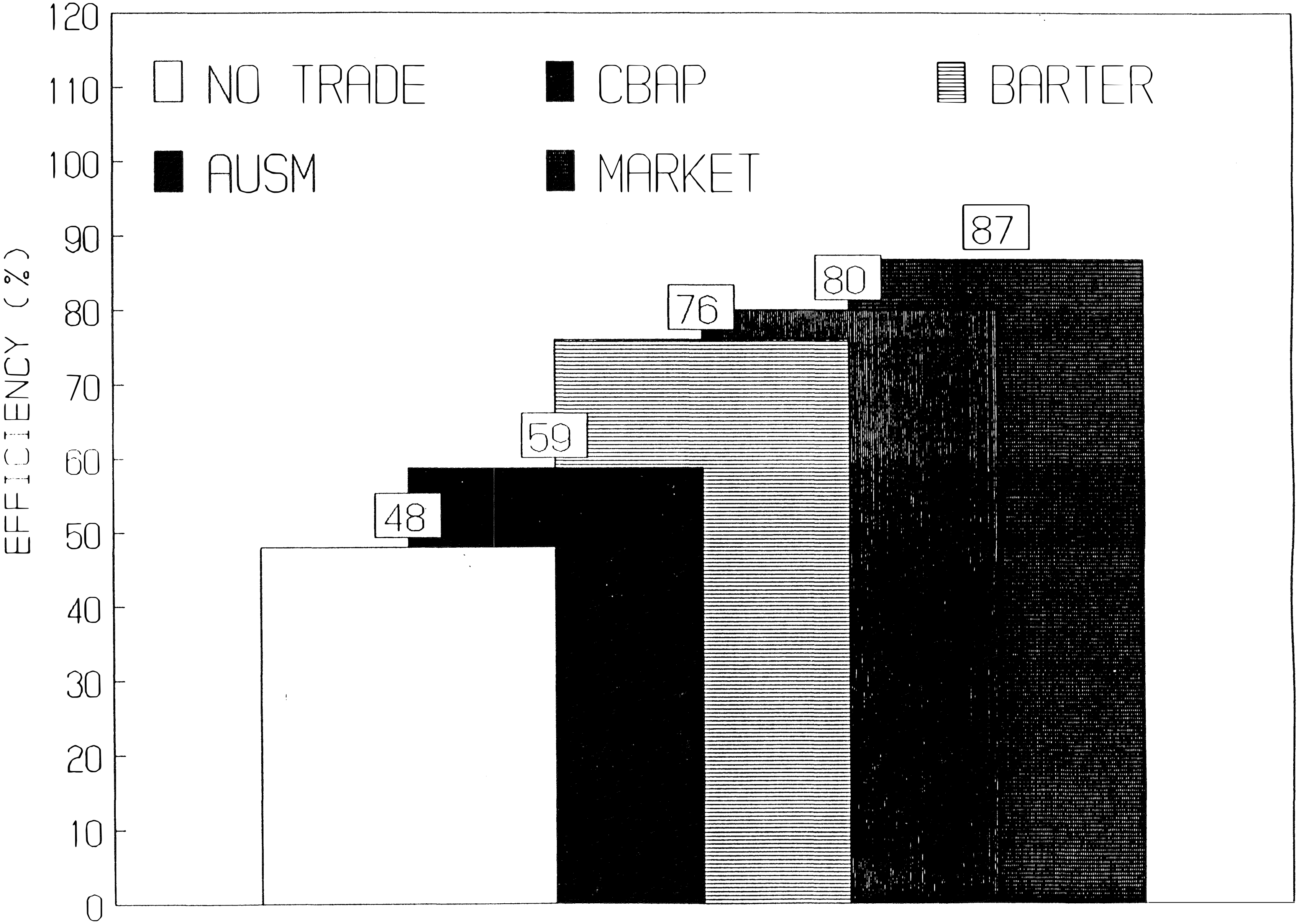
The per period average efficiency for each of the policies are shown in Figure 4. The "no trade" condition measures the efficiency of the initial endowment allocation used in the barter policy and the market policy. It is reported as one baseline for the effectiveness of barter and markets. As can be seen CBAP has the lowest efficiency (about 60 percent) and the market has the highest (about 87 percent). Barter and AUSM are similar but an average of the two series yields has a higher efficiency for AUSM (80.1 percent) as opposed to barter (76.1 percent).

Result 2. The market and Barter policies experience an increased efficiency with repetition. CBAP and AUSM remain virtually unchanged with repetition.

The time series of the average efficiency in each period is shown in Figure 5. If we compare the mean efficiency of periods less than three with periods more than three, we obtain the following statistics:

Periods	CBAP	Barter	AUSM	Market
1 - 3	59.4	73.7	81.7	83
> 3	58.0	77.3	78.3	89.3

FIGURE 4
AVERAGE EFFICIENCY



Observation 1. A cyclical pattern is apparent in the efficiency time series. However, this cycle is not uniform across experiments.

Analysis of Efficiency Performance

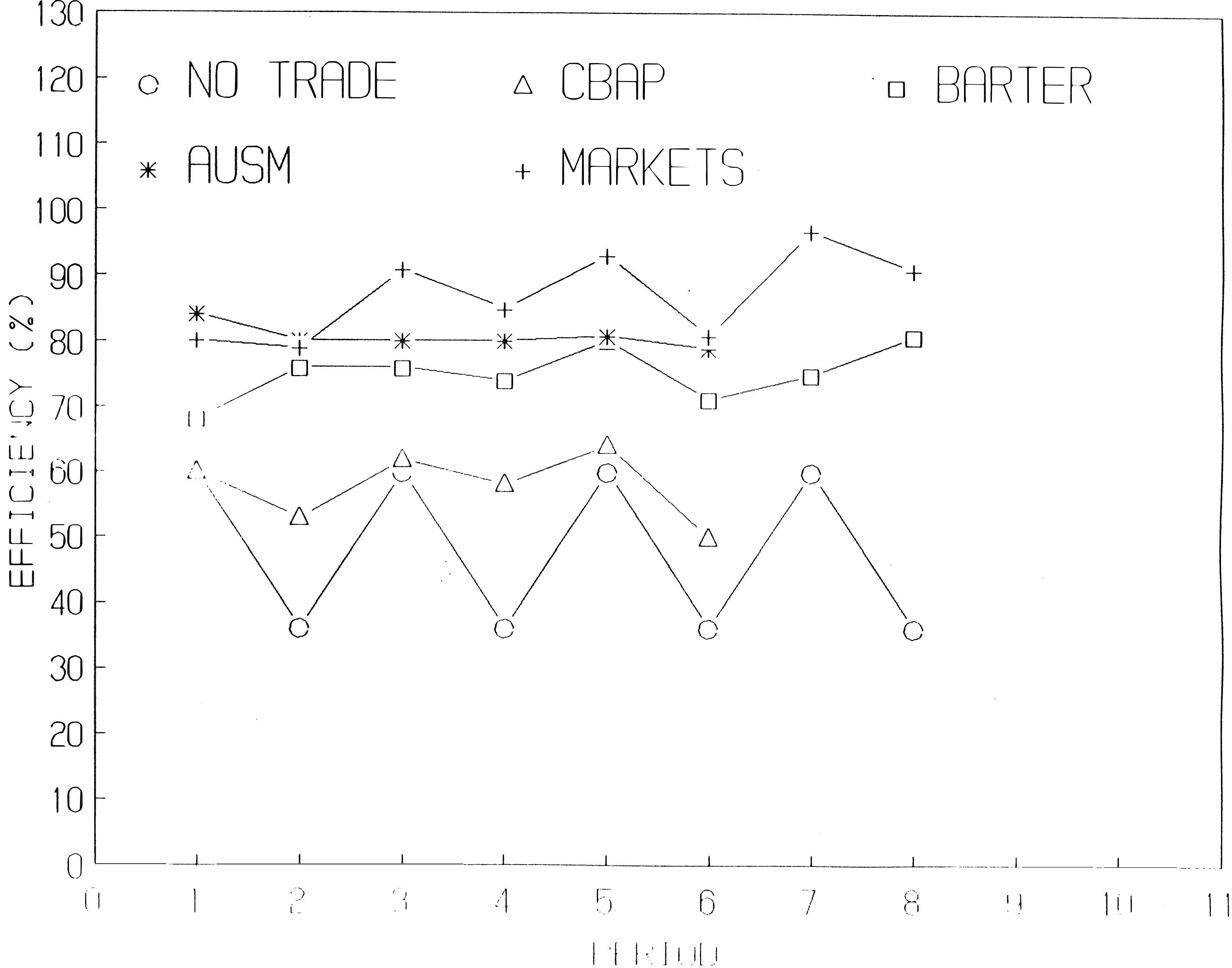
Inefficiencies can come from a variety of different sources. (Five sources are analyzed in this section.)

Station Resources Wasted. Wasted station resources consist of resources that are unallocated and resources that are allocated but not used. First, resources might be unallocated to users and just remain on the station with no one attempting to use them. Or, resources might be allocated to participants but remain unused in the sense that they are held by the agent even though the marginal returns are zero to the agent that holds them. Because all resources are allocated to participants in barter and market policies, only the second type of waste can occur. In CBAP and AUSM agents apply for resources. Applications for resources can fall short of the amount of resources that exist, so in these two policies both types of waste can occur.

Result 3. Wasted power and manpower contribute most to the inefficiency of the CBAP policy.

As can be seen in Figure 6 the waste of power and manpower is consistently larger in CBAP than for any other policy. In power, for example, the waste under CBAP was approximately 25 percent of rated station capacity. On the other hand the waste of power and manpower under the market policy was on average less than 2 percent of rated capacity. The waste of mass was low under all policies ranging from 3 percent to 8 percent of rated capacity. In this range the waste from barter was consistently higher than AUSM and markets. These data tell us that the mass constraint, the ability to transport projects to the station, was binding but the projects that got on the station were such that the other resources were in excess supply. Specifically, mass was a major component in a project's design and came in discrete amounts. Thus, Barter and CBAP both had problems in coordinating payload mass requirements.

FIGURE 5
AVERAGE EFFICIENCY TIME SERIES



Exclusion from Station. Each agent had a special project that could be interpreted as a ground project even though it was not labeled that way and subjects were not given that interpretation. The project required zero units of station mass launch capabilities (because the project stayed on the ground). The project could (technically) use other station resources (such as manpower or power) in performing special functions with station equipment or for relaying data to the ground, but for the most part choice of this special project meant that the project was on the ground.

Efficient allocation of station resources required that one particular agent should always choose the ground project. In an economic sense the agent was extramarginal and should be excluded from use of station resources. All other agents should be included in the sense that they should have projects on the station (i.e., choose projects other than the ground project).

Result 4. The separation of excluded and included agents is most effective in the market and AUSM policies and least effective in CBAP and barter.

Figure 7 shows the frequency of choice of the zero project by the extramarginal person and by other participants.

Project Design. For each agent the set of all projects can be described in terms of a set of design parameters. This leads to two different ways of describing the opportunity set of individual projects. The possible choices could be described as a set of different projects or the set could be described as only one project with several different design characteristics. We have tended to use the latter in this section.

The parameters are backup (yes or no), level of automation (a), and level of reliability (d). A project could be backed up with either mass such as spare parts or a duplicate subsystem. A project could also be backed up with manhours such as an astronaut who is trained to fix the project should it have a mishap. Backup guarantees that once a project is on the station it will operate at the most productive rate, assuming that station resources are available. Backed-up projects cannot experience individual failures. However, given the risk and given the opportunity cost of station resources the insurance provided by backup is too expensive. *Backup should never occur.* In the efficient allocation of resources no project should be backed up.

Figure 8 shows the average of each type of backup used expressed as a percentage of the total amount of that resource that is available. Figure 9 shows the average value of resources used as backup in terms of the competitive equilibrium prices.[8]

Result 5. Under CBAP, project designs tend to use backup more than under other policies.

The result is clear from the figures. More backup resources are used under CBAP and they tend to be the most valuable (priority one) resources. When backup occurs in the policies, other than CBAP, it is with the less valuable priority two resources.

Automation is a second parameter which fixes the project design. Automation is closely related to mass. Designs that are more automated have a higher marginal productivity of labor and also require more mass. Thus, if mass is inexpensive relative to labor, one would think that automation might occur to a higher degree. As mass becomes more expensive relative to labor, one would expect the designs to be characterized by less automation. Just the reverse would be true for the price of manhours and automation. In CBAP, for example, in which mass is priced low relative to the competitive equilibrium (0.25 as opposed to a competitive equilibrium price of 1.50), one might expect projects to be more automated.

As it turns out, features of the policies other than price have a substantial impact on automation. In particular, the way that resources are allocated in the manifest and the way resources are rationed in case there is a station failure have a big impact on design choice. CBAP has *agents* classified by priority, and does not designate resources by priority. This property affects the designs. High priority agents whose requests are filled first will automate more under CBAP than the other processes. Low priority agents, whose requests are filled after the requests of others,

8. This measure of the value of backup will tend to overstate the loss due to backup since it does not subtract out the opportunity cost of the use of the resource to an individual.

FIGURE 6
RESOURCE WASTE

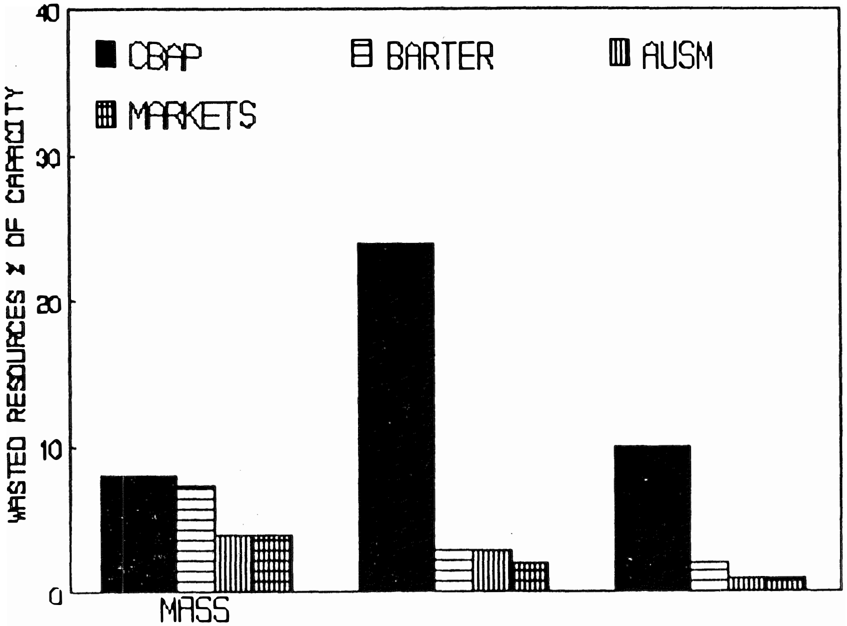


FIGURE 7
UTILIZATION OF GROUND PROJECT

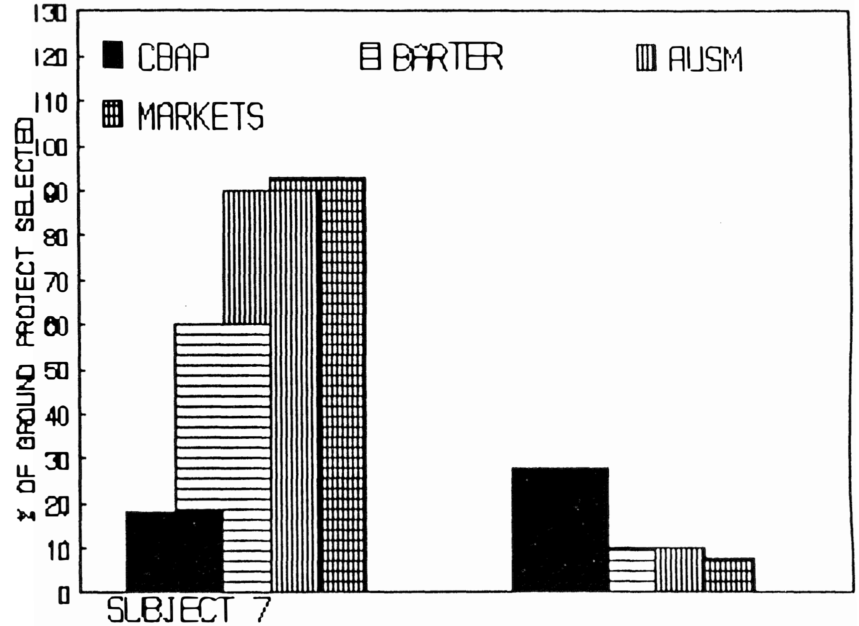


FIGURE 8
% OF BACKUP IN RESOURCE USE

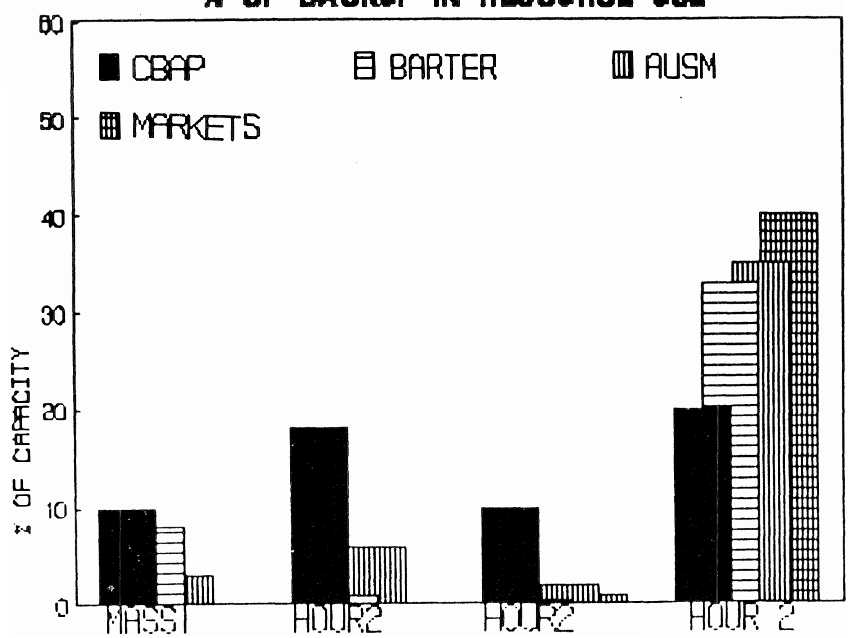
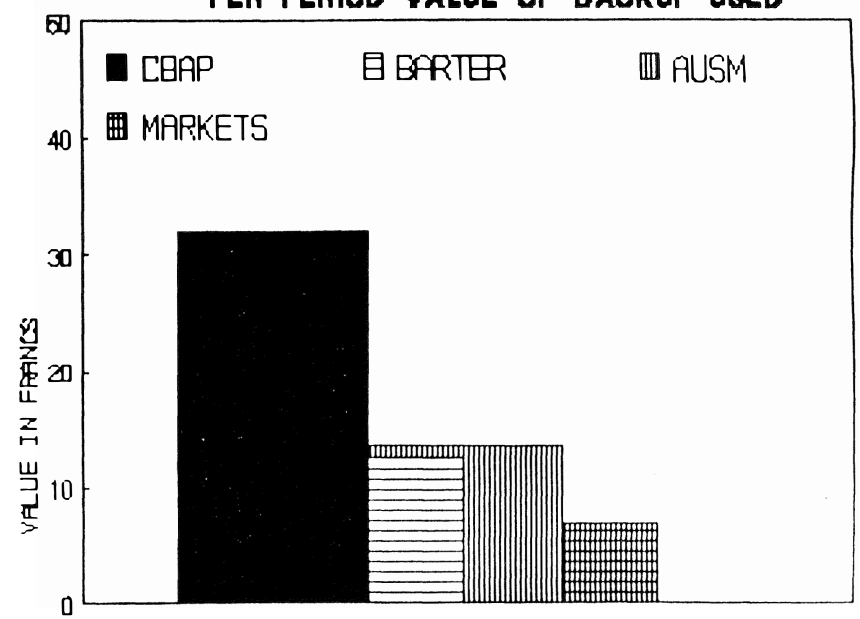


FIGURE 9
PER PERIOD VALUE OF BACKUP USED



automate less under CBAP in hope that some (small) amounts of mass will be left over for them to use.

Result 6. People designated as priority one people under CBAP automate more under CBAP than other processes. People designated as low priority agents under CBAP automate less under CBAP than in other processes.

Figure 10 contains data for priority one agents. Under CBAP these agents place over 45 percent of the projects in the highest two categories of automation. Under the other three policies these same people choose less than 20 percent of the projects from these two categories on average. Under CBAP the first priority agents never launched a project at the other end of the scale with the lowest level automation. Yet, under the other three policies these people choose an average of 10 percent of the projects at the lowest level of automation.

The radical shift of designs in response to the policy can also be seen in the behavior of the low priority agents as reported in Figure 11. Under CBAP low priority agents automate less, with almost all projects at the lowest two automation levels. Under the other three policies they automated significantly more. Thus, the behavior of the two groups is exactly the opposite.

C. Growth Signals

Each process provides different signals for growth. Two processes provide a source of revenue to support growth. The other processes only provide data and signals for an administrative decision about growth. Presumably the signals are related to a marginal cost and marginal benefit comparison. Since marginal costs have not been specified in the environment, the focus is on marginal benefits alone.

Four measures seem to be relevant to growth decisions: 1) the revenues generated by the sale of resources; 2) the market prices or implicit prices[9] in the case of AUSM; 3) resources wasted;

9. The implicit prices are those which form a least square fit in a model that uses bids as the dependent variable. Specifically, we estimated the model:

$$bid_i = \alpha_0 + \rho_1 \, mass \; 1_i + \rho_2 \, mass \; 2_i +$$

FIGURE 10
LEVEL OF AUTOMATION BY PRIORITY 1 SUBJECTS

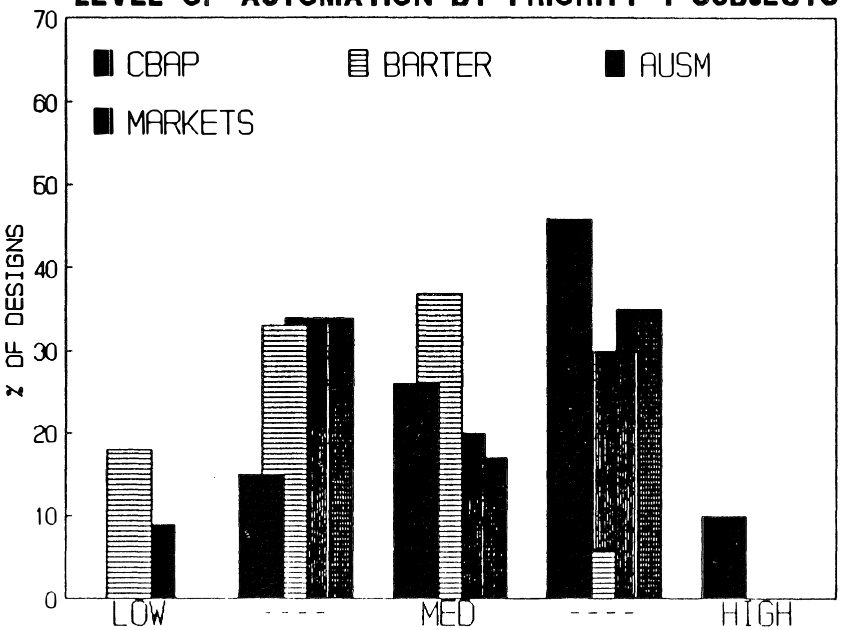


FIGURE 11
LEVEL OF AUTOMATION BY LOW PRIORITY SUBJECTS

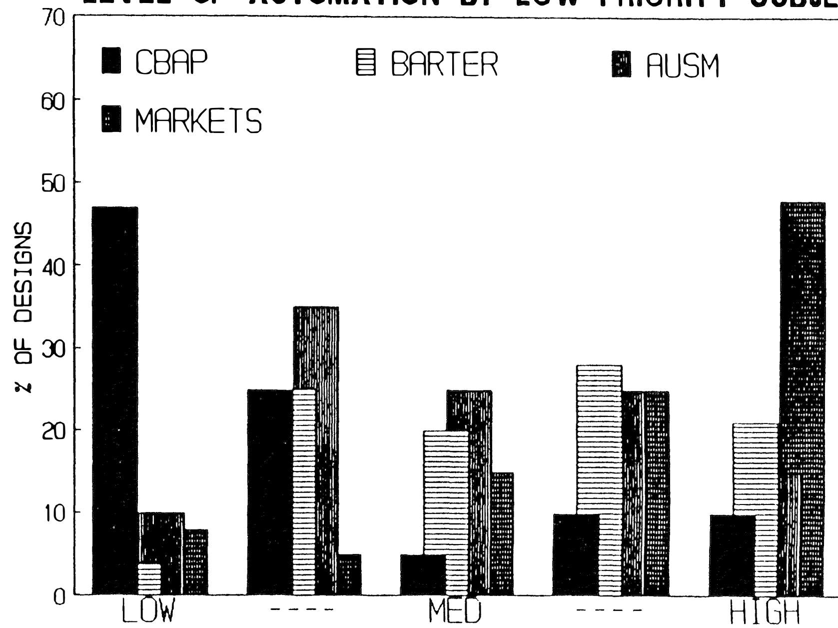


FIGURE 12
AVERAGE PER PERIOD REVENUE

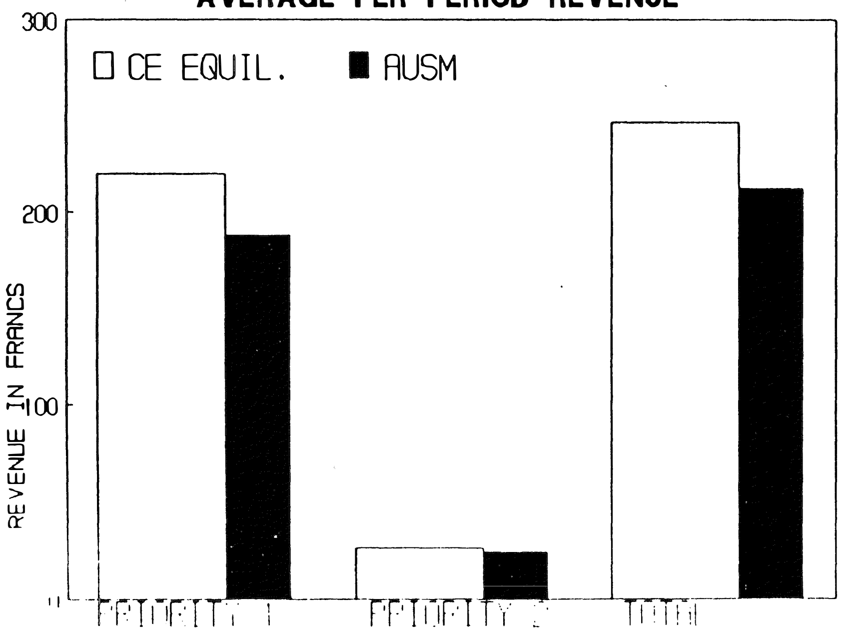
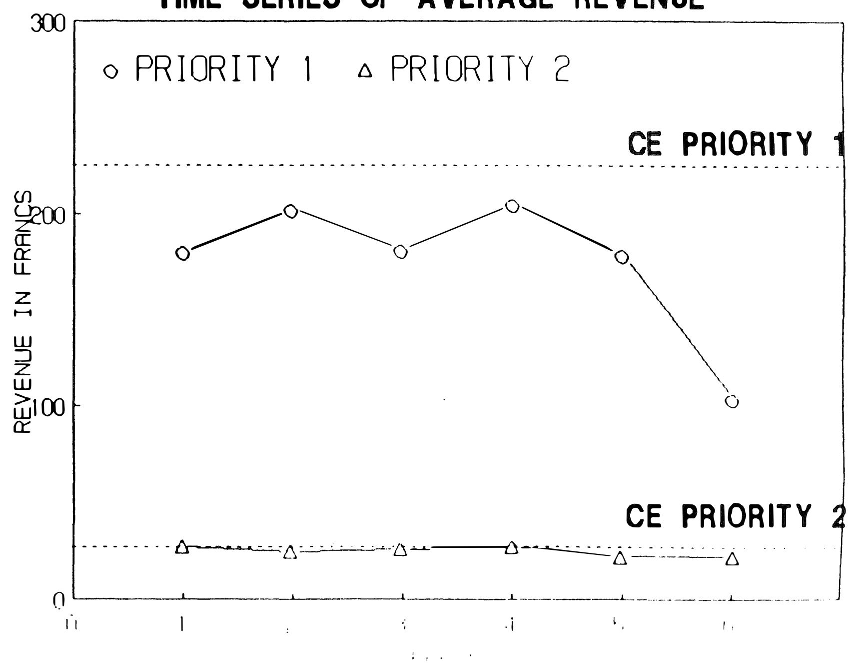


FIGURE 13
TIME SERIES OF AVERAGE REVENUE



and 4) resources requested. The first measure is relevant for AUSM and CBAP. The second measure is relevant to market and AUSM. All policies generate the third measure. The logic of the third measure is that the most valued resources will be wasted the least and therefore resources that are wasted the least should receive first priority in growth. The last measure is the amount of resources requested by those attempting to acquire resources. CBAP is the only policy for which this measure might be sensible.

In evaluating growth the question of increased station rated capacity must be separated from the question of reliability. For purposes of discussion, growth of a resource will mean only an increase in rated capacity and *not* an increase in the amount of priority one resources. It is as though a fixed number of resources will survive a station breakdown and *not* a proportion of capacity. Thus, growth will mean only an increase in priority two resources with priority one resources fixed. Increased reliability will mean an increase in priority one resources with rated capacity (priority one plus priority two) fixed.

The station revenue results are surprising only because AUSM failed to generate revenues equal to competitive equilibrium values. The fact the CBAP revenues are so small reflects the fact that the prices are not designed to be demand determined and therefore market clearing. Specifically, the result is:

Result 7. Revenue generated by AUSM is 550 percent greater than revenue CBAP. In terms of the level of revenue generated at the competitive equilibrium price we find on average revenue generated by AUSM is 90 percent of what would be theoretically generated if competitive equilibrium prices were charged.

The average per period revenue in Figures 12 and 13 make the point. As can be seen, each

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$$\gamma_2 \, Power\, 1_i + \gamma_2 \, Power\, 2_i +$$

$$\Psi_1 \, manhours\, 1_i + \Psi_2 \, manhours\, 2_i +$$

so that the estimates ($\hat{\beta}_1$, $\hat{\beta}_2$, $\hat{\gamma}_1$, $\hat{\gamma}_2$, $\hat{\Psi}_1$,¯ and $\hat{\Psi}_2$ are implicit resource prices).

period the revenues from AUSM lie between the revenues predicted by a competitive equilibrium model and the revenues generated by CBAP.

The next result is focused on the growth priorities that should be given different resources. Without cost considerations, which resources should be treated as the most important in terms of growth? Theoretically the order should be hours first, then power, and mass is last.

Result 8. All indices in market, AUSM, and barter give the correct ordering of growth priority. The signals are for highest priority manhours to be increased, followed by power and then mass. The two indices available in CBAP give an incorrect ordering. Mass, which should be given the lowest priority, is incorrectly given top priority.

In order to check the results, study Table 4. The correct ordering is given by the marginal values of resources at the optimum allocation (the competitive equilibrium). Each index is provided for each policy. The higher price of a resource is interpreted as a higher marginal value and thus higher priority (recall that only priority two is relevant for capacity expansion). A check on prices in market and AUSM reveals that the values of prices are as required for the result. A similar check on the values of wasted resources in all four policies gives the result. Recall that a higher value of waste implies a lower priority for growth. CBAP has one index (requested resources) not available to the other two. If greater requests of resources imply greater priority for growth, then this index does not generate the true priorities.

Growth priorities do not carry all of the information necessary for a growth decision. The value of expansion must be compared to cost. The actual magnitudes of benefits must be compared to the true benefits.

Result 9. In market policy the values of growth tend to be overstated and in AUSM the values tend to be understated.

The only exceptions to the result are power 2 and mass 2 in AUSM which have revealed marginal values of .27 and 4.41. The true values at the optimum are mass 2 = .15 and power 2 =

TABLE 4

GROWTH POTENTIAL MEASURES: PER PERIOD AVERAGES FOR ALL RESOURCES

		M_1		M_2	P_1		P_2	H_1		H_2
Theory	Station revenues	260								
	Resource prices	1.50		.25	3.55		1.15	4.67		1.60
Market	Station revenue [1]									
	Resource prices (average)	1.81		.50	4.95		1.60	6.55		2.25
	Resource waste [3]		4.5%			1.0%			0.5%	
	Resource requested [1]									
AUSM	Station revenues	235								
	Resource prices (implicit)	.88		.27	4.41		.49	3.91		1.54
	Resource waste [3]		3.0%			2.7%			1%	
	Resource requested		98%			100%			100%	
Barter	Station revenues [1]									
	Resource prices [2]									
	Resource waste [3]		8%			3%			2%	
	Resource requested [1]									
CBAP	Station revenues	38								
	Resource prices [2]									
	Resource waste [3]		8%			24%			10%	
	Resource requested		134%			98%			116%	

1 Resources were distributed free of charge.

2 The system generated no prices.

3 Resource waste does not include backup losses.

3.55.

Only market and AUSM provide measures of the value of increased reliability. If overall capacity is fixed, then increased reliability is equivalent to shifting one unit of a resource from priority two to priority one. Thus the opportunity cost of a priority one resource is the value of the priority two resource foregone. And, the resulting value of the priority two resource is the difference at the margin between priority one resources and priority two. This difference gives the marginal value of taking some action that increases reliability while leaving rated resource capacity fixed.

Result 10. At the social optimum the marginal value of increased liability for manhours, power, and mass are 2.90, 2.40, and 1.35, respectively. The comparable magnitudes under market are 4.30, 3.35, 1.31, respectively, and under AUSM are 2.37, 3.92, .61, respectively.

When comparing overall the priorities given by the market, policies differ from the social optimum in the order of priority between increased power and increased reliability of mass. Under AUSM the only difference in order is between increased reliability of manpower and power. Aside from these two differences market and AUSM generate the same priorities for action. However, the overall magnitudes are higher than optimal in market and lower than optimal in AUSM.

RESULTS; MODEL EVALUATION

This section attempts to focus on two of the broad questions posed in the introduction. Do we understand what happened? What might be done to improve the policies?

Markets

Figures 14-19 contain the time series of the mean transaction prices and volume made in the markets for each experiment (labeled series 1, 2, or 3 in the figures). Recall that eighteen markets were open simultaneously (three resources times two priorities times three periods). The figures show that all eighteen resource markets contain some irregularities relative to the convergence patterns usually observed in less complicated markets. Priority one mass in series 2

FIGURE 14

MEAN CONTRACT PRICE AND RANGE

Mass: Priority 1

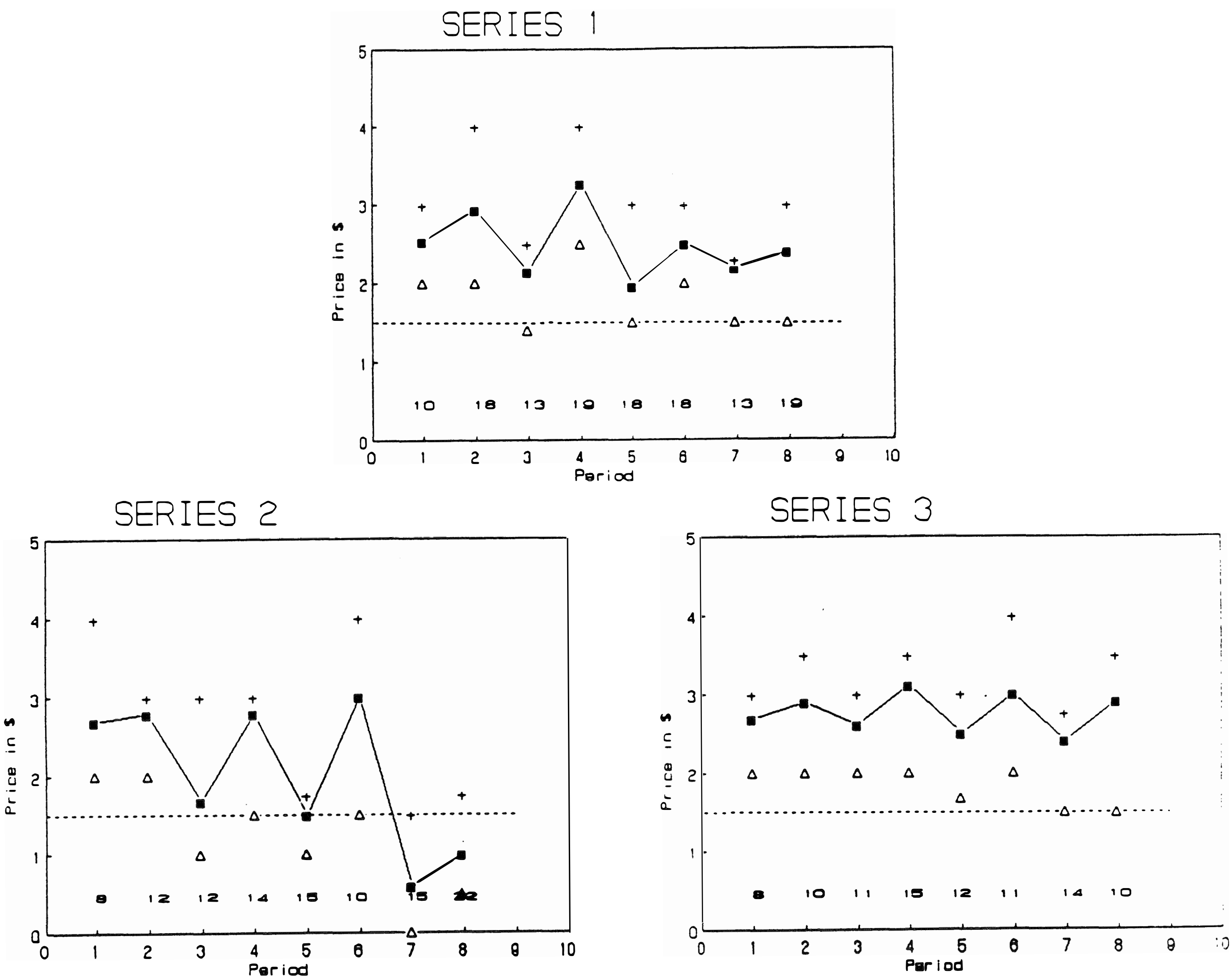


FIGURE 15

MEAN CONTRACT PRICE AND RANGE

Power: Priority 1

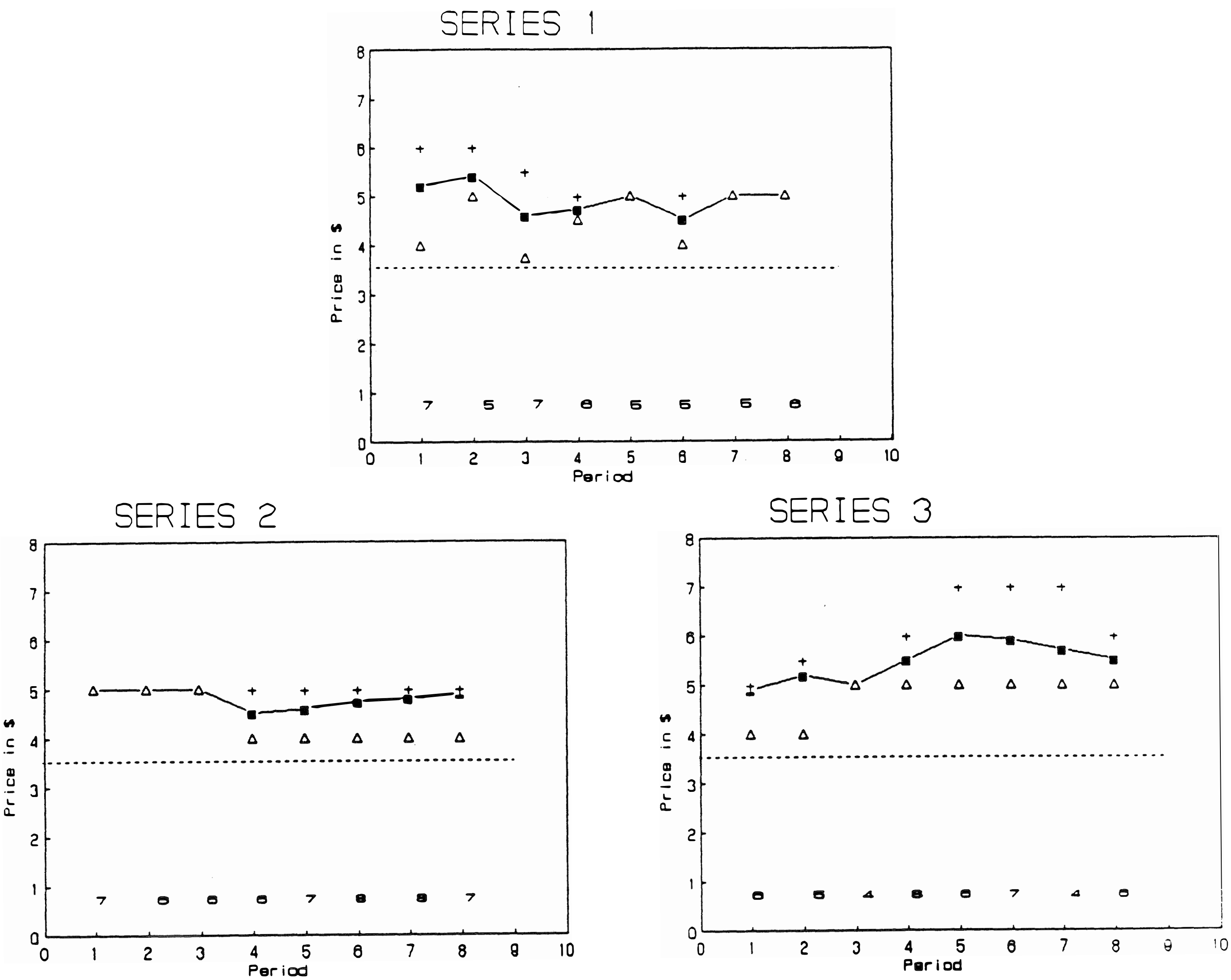


FIGURE 16

MEAN CONTRACT PRICE AND RANGE

Manhours: Priority 1

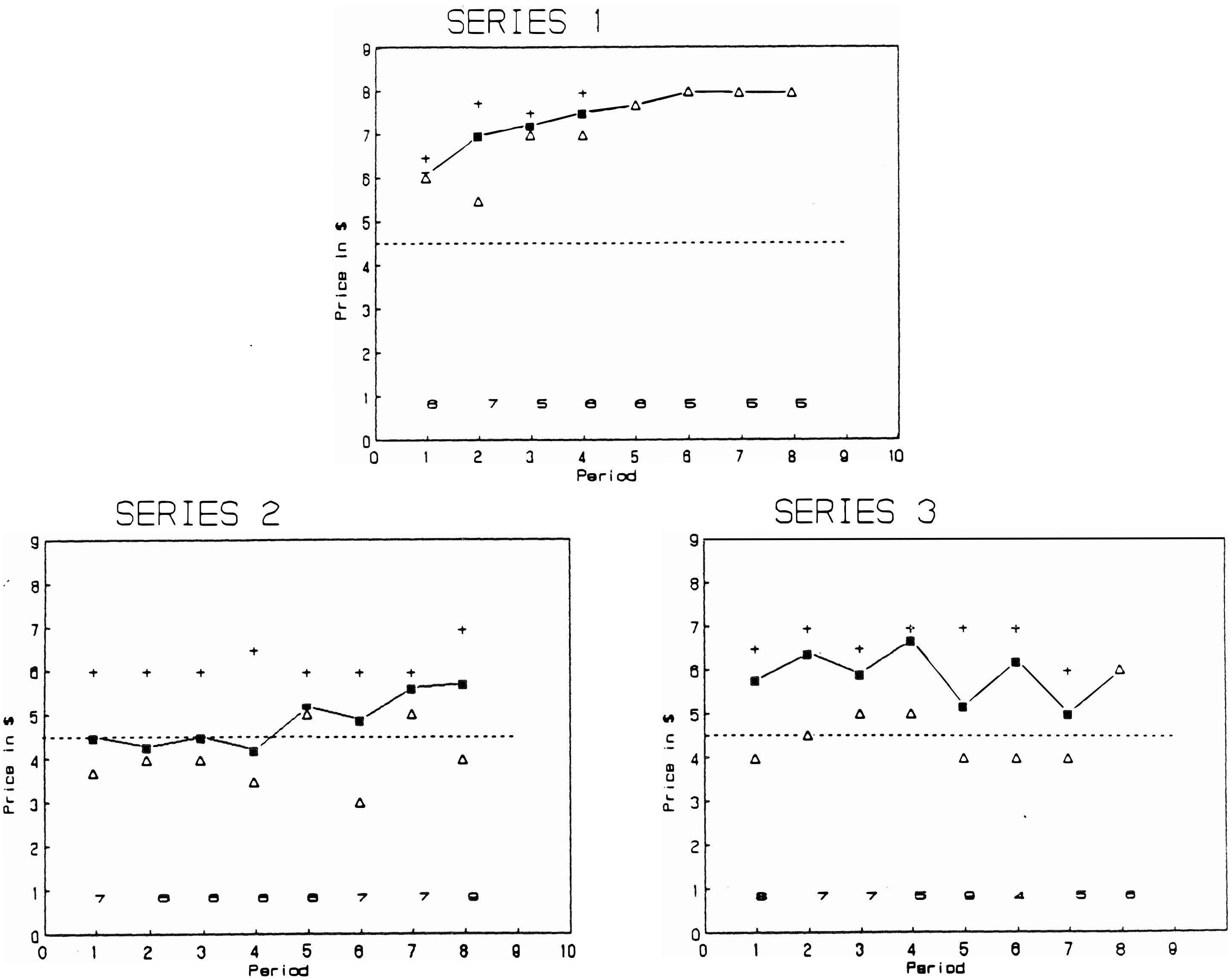


FIGURE 17

MEAN CONTRACT PRICE AND RANGE

Mass: Priority 2

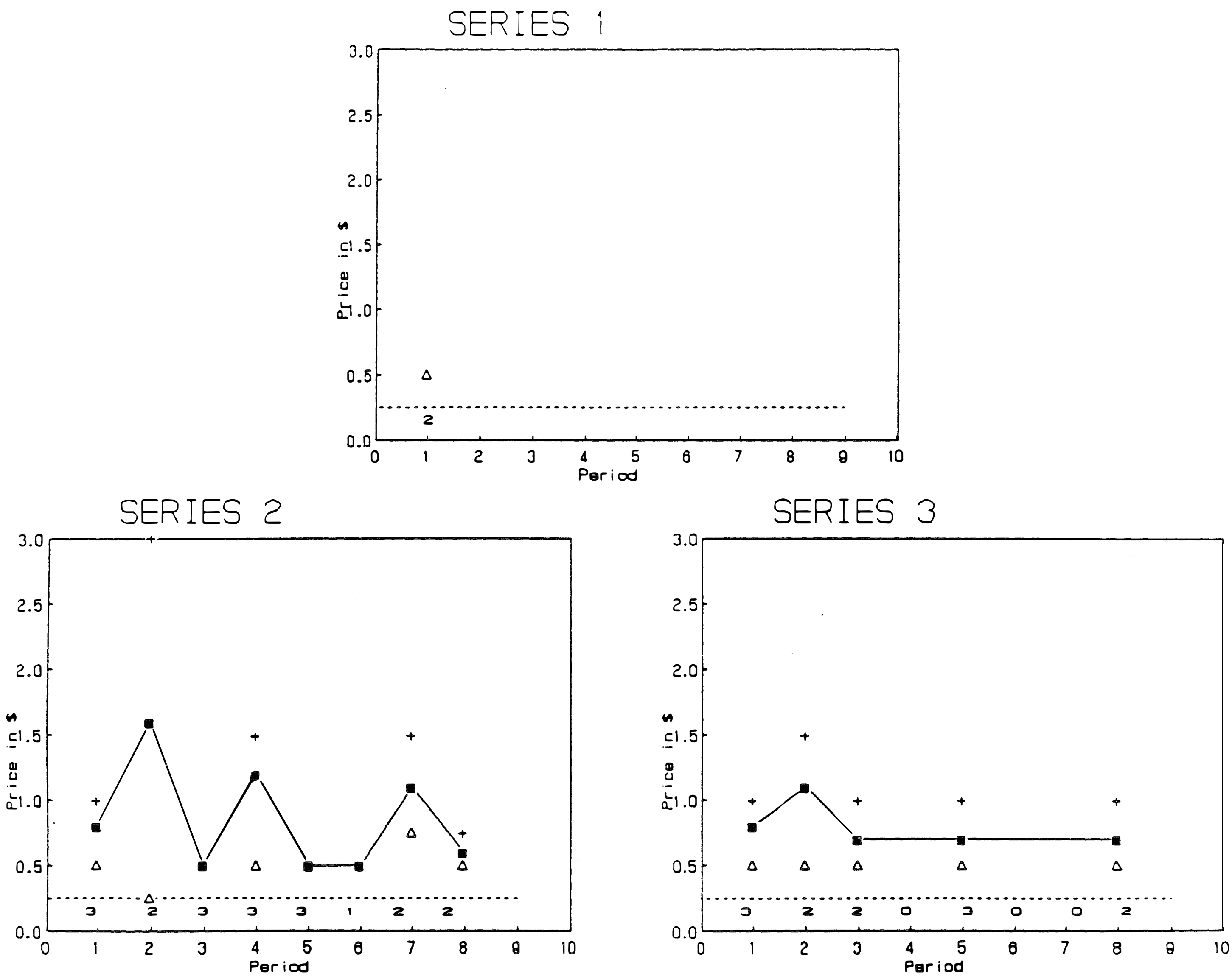


FIGURE 18

MEAN CONTRACT PRICE AND RANGE

Power: Priority 2

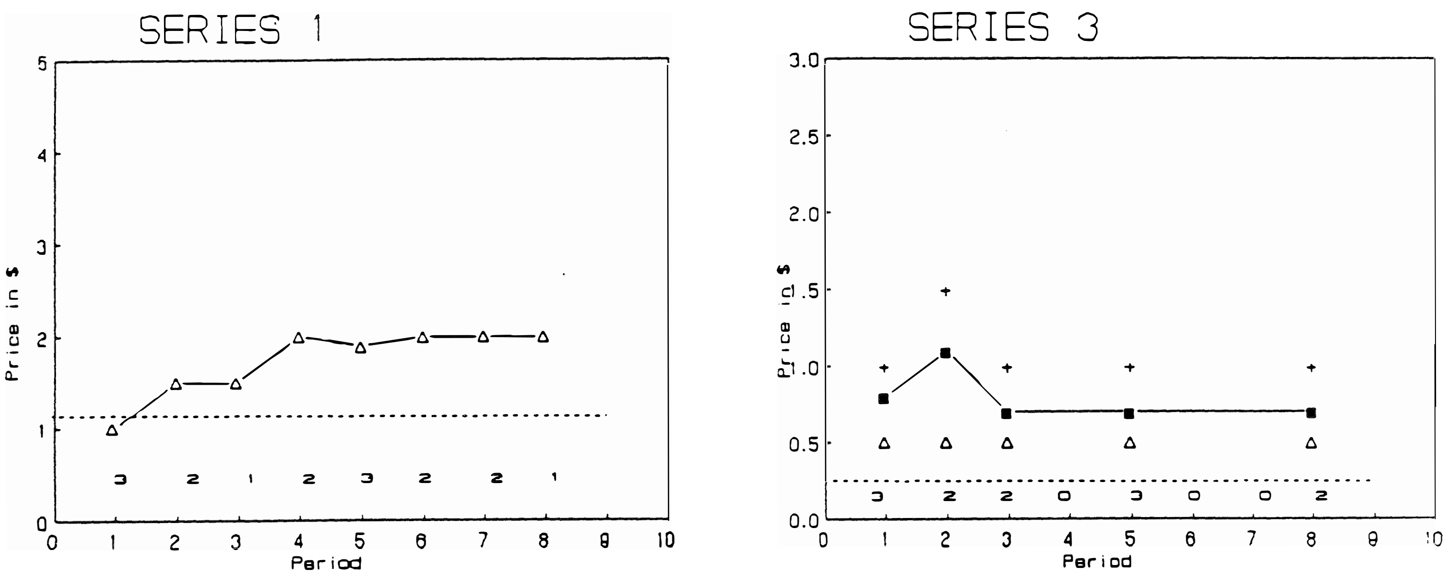
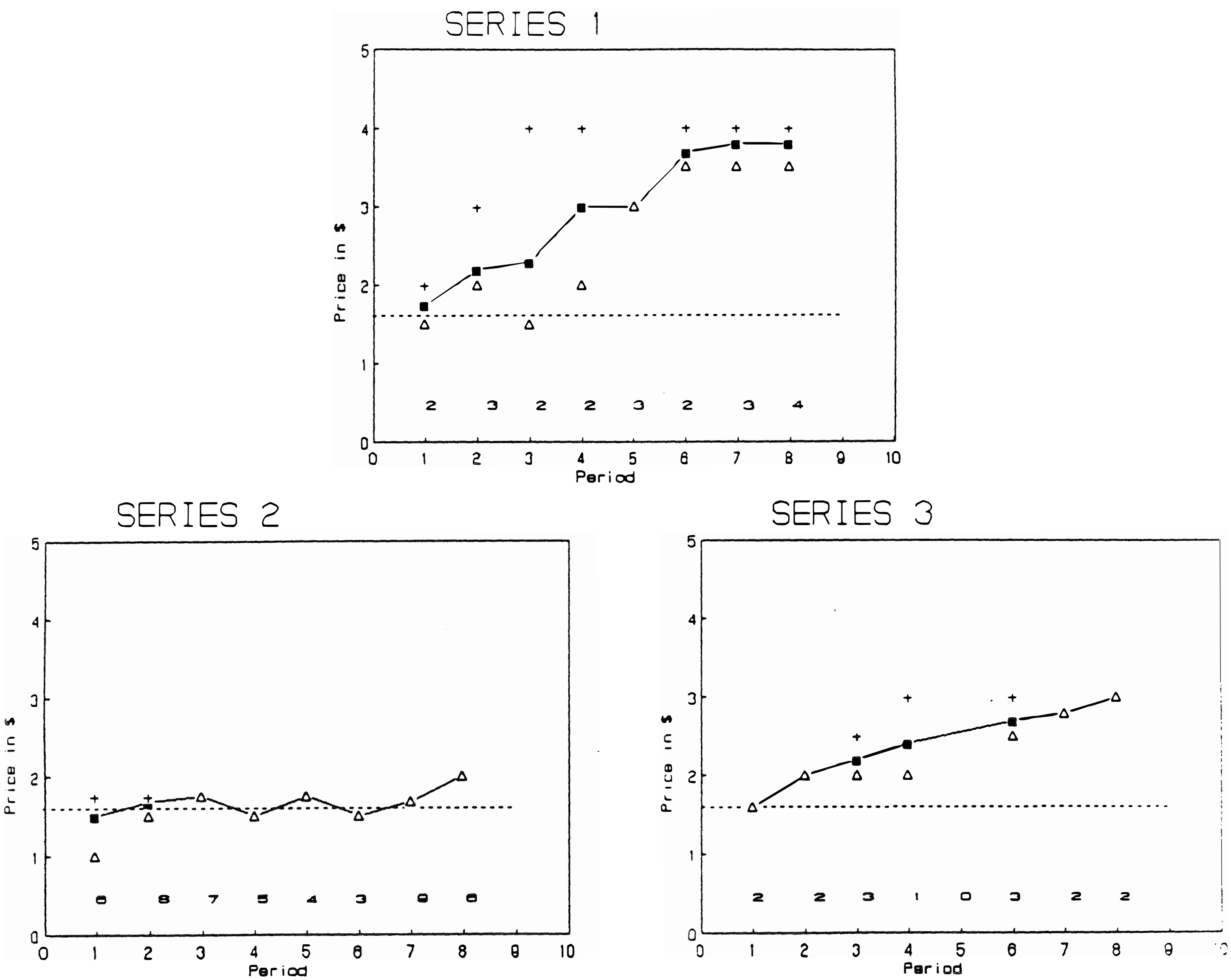


FIGURE 19

MEAN CONTRACT PRICE AND RANGE

Manhours: Priority 2



converges to prices below the competitive equilibrium. Priority two mass in series one hardly trades at all. In both series priority one power is priced above expectations while priority two power does not trade. Manhours trade at their prices higher than expected in both series.

Currently we have no explanation for these deviations from expectations. On one hand, given the complicated setting, we have no baseline for what to expect. Certainly prices are within an order of magnitude of predictions. Bubbles or wide speculation and swings do not appear to occur. We have found no biases resulting from the fact that the price predictions result from an expected value calculation.

Of considerable interest is the behavior of the futures markets. The exceptional markets are Series 1 power and Series 1 manpower in which the futures markets were used only once in a total volume of 129 units traded. By contrast the volume in all other markets was completely dominated by futures trading. Neglecting period 1 resources, which cannot be traded as futures, the proportion of trades in priority 1 markets that are futures contracts are: 67% mass 1, 49% power 1, 56% manhours 1.

The pattern suggests that future markets are not good predictors of spot prices. The volume of future trades is for delivery as opposed to speculative resale. The bulk of transactions are made far in advance. Spot markets are then reserved for "clean up" trades due to miscalculations or due to mistakes that need last minute corrections and the prices can deviate sharply from the historical patterns.

Less trading than expected occurred in the priority two markets. Why this occurred is an open question. Nevertheless, the priority instrument as a contingent market seemed to work smoothly. The prices, given the prices of priority one sources and risk aversion, seem "reasonable."

AUSM

The allocation with 100 percent efficiency can be supported as a Nash equilibrium. This allocation never occurred in either series. As was discussed in an earlier section, the existence of other Nash equilibria is suspected. The stable level of efficiency in the experiments suggests that it may be too hard to coordinate demands to get to 100% efficiency with the current AUSM technology.

Barter

Since experiments with barter have never before been conducted, the global observations should be made. Trade actually occurs. Search for trading partners does not continue for the whole period. The negotiations version of a "strike" or no trade default positions do not occur.

Traders are position improving in the sense that all participants are made better off by virtue of trading. Of the 113 cases of individual initial endowments, 97 are better off at the end of that period or are more than twice as well off at the end of the next period. The basic gains from trade propositions can be observed in operation.

For the most part barter was smoother than expected. Efficiency levels rivaled AUSM in experiment 1. This leads to questions about the robustness of the result in different environments. The number of potential traders might be important. The existence of a need for "chains" of traders might also be important. In the current environment each trader has some of every resource so direct trades were always a possibility. If a need for a third or fourth party was necessary for a transaction, the process might not be so efficient.

The efficiency of the process also raises another question. Could it be improved upon? Perhaps some sort of organized exchange or internal medium of exchange (as opposed to U.S. currency) might improve the process.

CBAP

The CBAP policy demonstrates a fundamental problem with marginal cost pricing or indeed any cost based pricing policy. If lags in supply occur and if excess demand exists while the process is determining a supply response, rationing problems exist. The solutions to the rationing problems affect not only the allocation of resources and the value to which space resources are put, they also affect the signals for future growth and expanded supply. Demand-based pricing systems are far superior.

The particular method of dealing with the rationing problem that has evolved into the space shuttle pricing policies adds to the problems caused by cost-based pricing. Priority is given to a source of demand or type of agent. Priority is not treated as a type of resource. As a result the method of allocating the scarce resources and resolving the uncertainties has a feedback on the projects that are selected and the project designs.

Priority one agents choose to automate. Agents with lower priorities do not automate. The reason is because automation uses mass and low priority agents face a tradeoff between mass use and the probability of having a project on the manifest. The bigger the project the less chance of manifest. Thus, low priority agents choose smaller designs.

An interesting phenomenon called the "gas can" has been observed in shuttle. Low priority investigators have been avoiding large projects which seem to have large benefits and are proposing small projects instead. In a sense the projects are the size of gas cans and have the capacity to fit in the bay of shuttle along with larger projects placed on shuttle by higher priority agents. The phenomenon has been attributed to the shuttle pricing policy from which CBAP was fashioned.

We have been able to produce a similar phenomenon in our experiments. Low priority agents choose low mass projects. High priority agents choose big projects. In our experiments the phenomenon is definitely attributable to the priority system used in CBAP coupled with prices so low that demand needs to be rationed by other means. The means of rationing by priority of agents affects the projects chosen.

CONCLUSIONS

It is important to remember that this study focused on only one point in a very large parameter space. It is hoped that the results from this first "test bed" will lead to discussions that will result in judgements about which points should be considered next. How should the environment be changed to help with a more informed judgement about how alternative policies would work?

All of the policies explored here are complete relative to the testbed environment. All policies worked in the sense that decisions were made. Unanticipated behaviors caused no problems. Administratively CBAP is the most difficult. It is also the policy that is liked least by participants (see Table 5). Even the first priority agents who had the most to gain from the CBAP policy gave it low marks.

None of these policies are complete relative to more complicated environments. The down manifest was ignored. Storage on station and the related capacity limitations were not considered. However, both of these problems seem sufficiently similar to problems found in the environment now that their inclusion will be only a complicating elaboration as opposed to changes that might challenge the basic principles which underline the policies. Two sources of externalities are likely to exist that are not elaborations on what has been studied here and might require special policies. Some projects can be incompatible in the manifest. Other projects might be incompatible on the station. The processes examined here make no provision for dealing with such problems. Another potential source of policy incompleteness is the determination of the number and nature of priority classes of resources. Currently the policies reflect no principle for making that determination.

Do we understand the pattern of results generated by the policies? Clearly every detail of such a complicated situation cannot be fully understood but the data yield no major surprises. For anyone who has studied the behavior of experimental markets the behavior of *eighteen simultaneous markets* certainly presents interesting phenomena. The fact that prices were on the same order of magnitude as the prediction of the competitive model suggests the power of that model as an explanation of the general patterns. In all cases the patterns of resource flows are understandable in terms of the models employed.

Natural comparisons exist among the policies. Given an initial distribution of resources, a

TABLE 5

THE NUMBER OF PEOPLE WHO RANKED THE PROCESS FIRST AMONG THE FOUR PROCESSES ACCORDING TO THE GIVEN QUESTION

	Q_1	Q_2	Q_3	Q_4	Q_5
Market	6	7	10	4	9
Barter	6	5	3	8	5
AUSM	1	0	1	2	3
CBAP	1*	3*	0	0	0

Q_1 Which one would you choose to use?

Q_2 Which one was most profitable?

Q_3 Which one worked the best?

Q_4 Which one was most fun?

Q_5 Which one was most fair?

* These were priority one people under CBAP.

policy of market reallocation is superior to a policy of barter. The use of a medium of exchange facilitates coordination. However, a policy of barter is much superior to a policy of no trading or a policy of not permitting any decentralized adjustment subsequent to the initial allocation. Resale or retrading of resources should not be discouraged. In fact NASA should help organize such exchanges.

Both AUSM and CBAP involve an initial sale of resources. The AUSM process is clearly superior in all dimensions. Not only does CBAP not facilitate efficient resource allocation, it also gives the wrong signals for growth. If resources are to be sold initially, then AUSM should be seriously considered as a candidate for allocating the station's resources to commercial users.

Fundamental to the operations of these policies is the method of dealing with supply uncertainty. A priority resource contract should be employed. Priority should be defined in terms of resources and not the particular user. Reliability of supply is itself a scarce resource that should be reflected in all decisions and policies.

APPENDIX A

Experiment Parameters

Subject 1

	A	B*	C	D	E
automation (a)	2.00	1.00	1.00	.50	0.00
durability (d)	10.00	10.00	30.00	10.00	0.00
mishap revenue (γ_o)	.75	.75	.75	.75	.75
neta (n)	-.57	-.57	0.57	-.57	-.57
automation mass (m_a)	3.00	3.00	3.00	3.00	3.00
durability mass (m_d)	.1	.1	.1	.1	.1
gamma 3	.7	.7	.7	.7	.7
alpha 1	7.26	7.26	7.26	7.26	1.00
gamma 1	.63	.63	.63	.63	.14
alpha 2	17.05	17.05	17.05	17.05	17.05
gamma 2	1.88	1.88	1.88	1.88	1.88
gamma 4	.22	.22	.22	.22	.00
cm	4.27	4.27	4.27	4.27	.20
automation cost (c_a)	19.47	19.47	19.47	19.47	19.47
durability cost (c_d)	.22	.22	.22	.22	.22
backup manhours (bh)	2.00	2.00	2.00	2.00	2.00
backup mass (bm)	22.00	22.00	22.00	22.00	22.00
max power ($\overline{p}$)	4.00	4.00	4.00	4.00	4.00
min power ($\underline{p}$)	0.00	0.00	0.00	0.00	0.00
max manhours ($\overline{h}$)	4.00	4.00	4.00	4.00	4.00
min manhours ($\underline{h}$)	0.00	0.00	0.00	0.00	0.00
initial cost (c_o)	42.10	21.67	26.10	11.94	3.50
group cost (c_g)	2.0	2.0	2.0	2.0	2.0
slip cost (c_s)	8.0	8.0	8.0	8.0	8.0
in-flight cost (c_f)	2.5	2.5	2.5	2.5	2.5
max operating periods (o)	2.0	2.0	2.0	2.0	2.0
min development time (θ)	1.0	1.0	1.0	1.0	1.0
probability of slip	.25	.25	.25	.25	.25
probability of mishap (σ)	.25	.25	.14	.25	1.0
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	7.0	4.0	6.0	3.0	0.0
pi foot (π)	22.0	22.0	22.0	22.0	22.0
max mass ($\overline{m}$)	10.0	10.0	10.0	10.0	9.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 2

	A	B	C	D*	E
automation (a)	1.0	0.0	4.0	2.0	2.0
durability (d)	5.0	0.0	5.0	5.0	10.0
mishap revenue (γ_o)	.85	.85	.85	.85	.85
neta (n)	-.62	-.62	-.62	-.62	-.62
automation mass (m_a)	2.0	2.0	2.0	2.0	2.0
durability mass (m_d)	.2	.2	.2	.2	.2
gamma 3	.5	.5	.5	.5	.5
alpha 1	5.72	1.00	5.72	5.72	5.72
gamma 1	.22	.14	.22	.22	.22
alpha 2	8.09	8.09	8.09	8.09	8.09
gamma 2	1.25	1.25	1.25	1.25	1.25
gamma 4	.30	.00	.30	.30	.30
cm	6.33	.20	6.33	6.33	6.33
automation cost (c_a)	2.33	2.33	2.33	2.33	2.33
durability cost (c_d)	.01	.01	.01	.01	.01
backup manhours (bh)	2.0	2.0	2.0	2.0	2.0
backup mass (bm)	6.0	6.0	6.0	6.0	6.0
max power ($\overline{p}$)	9.0	9.0	9.0	9.0	9.0
min power ($\underline{p}$)	2.0	2.0	2.0	2.0	2.0
max manhours ($\overline{h}$)	4.0	4.0	4.0	4.0	4.0
min manhours ($\underline{h}$)	0.0	0.0	0.0	0.0	0.0
initial cost (c_o)	5.38	2.60	12.37	7.66	7.76
group cost (c_g)	2.50	2.50	2.50	2.50	2.50
slip cost (c_s)	5.00	5.00	5.00	5.00	5.00
in-flight cost (c_f)	2.00	2.00	2.00	2.00	2.00
max operating periods (o)	1.00	1.00	1.00	1.00	1.00
min development time (θ)	2.00	2.00	2.00	2.00	2.00
probability of slip	.33	.33	.33	.33	.33
probability of mishap (σ)	.33	1.0	.33	.33	.23
initial mass (m_o)	0.0	0.0	0.0	0.0	0.00
primary mass	3.0	0.0	9.0	5.0	6.0
pi foot ($\underline{\pi}$)	30.0	30.0	30.0	30.0	30.0
max mass ($\overline{m}$)	11.0	9.0	11.0	11.0	11.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 3

	A*	B	C	D	E
automation (a)	3.0	0.0	3.0	5.0	3.0
durability (d)	8.0	0.0	80.0	8.0	24.0
mishap revenue (γ_o)	.75	.75	.75	.75	.75
neta (n)	-.32	-.32	-.32	-.32	-.32
automation mass (m_a)	3.0	3.0	3.0	3.0	3.0
durability mass (m_d)	.25	.25	.25	.25	.25
gamma 3	.5	.5	.5	.5	.5
alpha 1	5.82	1.00	5.82	5.82	5.82
gamma 1	.57	.14	.57	.57	.57
alpha 2	8.42	8.42	8.42	8.42	8.42
gamma 2	.45	.45	.45	.45	.45
gamma 4	.91	.00	.91	.91	.91
cm	9.50	.20	9.50	9.50	9.50
automation cost (c_a)	5.31	5.31	5.31	5.31	5.31
durability cost (c_d)	.04	.04	.04	.04	.04
backup manhours (bh)	5.00	5.00	5.00	5.00	5.00
backup mass (bm)	25.00	25.00	25.00	25.00	25.00
max power ($\overline{p}$)	4.00	4.00	4.00	4.00	4.00
min power ($\underline{p}$)	0.0	0.0	0.0	0.0	0.0
max manhours ($\overline{h}$)	9.0	9.0	9.0	9.0	9.0
min manhours ($\underline{h}$)	2.0	2.0	2.0	2.0	2.0
initial cost (c_o)	16.25	2.3	20.13	27.87	17.89
group cost (c_g)	7.0	7.0	7.0	7.0	7.0
slip cost (c_s)	10.0	10.0	10.0	10.0	10.0
in-flight cost (c_f)	5.0	5.0	5.0	5.0	5.0
max operating periods (o)	1.0	1.0	1.0	1.0	1.0
min development time (θ)	1.0	1.0	1.0	1.0	1.0
probability of slip	.15	.15	.15	.15	.15
probability of mishap (σ)	.5	1.0	.25	.5	.35
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	11.0	0.0	29.0	17.0	15.0
pi foot ($\underline{\pi}$)	34.0	34.0	34.0	34.0	34.0
max mass ($\overline{m}$)	6.0	6.0	6.0	6.0	6.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 4

	A	B	C*	D	E
automation (a)	4.0	2.0	4.0	0.0	6.0
durability (d)	3.0	12.0	12.0	0.0	12.0
mishap revenue (γ_o)	.65	.65	.65	.65	.65
neta (n)	-.76	-.76	-.76	-.76	-.76
automation mass (m_a)	2.0	2.0	2.0	2.0	2.0
durability mass (m_d)	.2	.2	.2	.2	.2
gamma 3	.8	.8	.8	.8	.8
alpha 1	17.89	17.89	17.89	1.00	17.89
gamma 1	1.57	1.57	1.57	.14	1.57
alpha 2	5.54	5.54	5.54	5.54	5.54
gamma 2	.61	.61	.61	.61	.61
gamma 4	.17	.17	.17	.00	.17
cm	3.80	3.80	3.80	.20	3.80
automation cost (c_a)	4.42	4.42	4.42	4.42	4.42
durability cost (c_d)	.28	.28	.28	.28	.28
backup manhours (bh)	3.0	3.0	3.0	3.0	3.0
backup mass (bm)	24.0	24.0	24.0	24.0	24.0
max power ($\overline{p}$)	6.0	6.0	6.0	6.0	6.0
min power ($\underline{p}$)	2.0	2.0	2.0	2.0	2.0
max manhours ($\overline{h}$)	5.0	5.0	5.0	5.0	5.0
min manhours ($\underline{h}$)	0.0	0.0	0.0	0.0	0.0
initial cost (c_o)	18.52	12.20	21.04	2.50	29.88
group cost (c_g)	5.0	5.0	5.0	5.0	5.0
slip cost (c_s)	12.0	12.0	12.0	12.0	12.0
in-flight cost (c_f)	5.0	5.0	5.0	5.0	5.0
max operating periods (o)	2.0	2.0	2.0	2.0	2.0
min development time (θ)	1.0	1.0	1.0	1.0	1.0
probability of slip	.5	.5	.5	.5	.5
probability of mishap (σ)	.35	.14	.14	1.0	.14
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	9.0	7.0	10.0	0.0	15.0
pi foot ($\underline{\pi}$)	33.0	33.0	33.0	33.0	33.0
max mass ($\overline{m}$)	12.0	12.0	12.0	9.0	12.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 5

	A	B	C	D	E*
automation (a)	2.0	4.0	0.0	0.5	2.0
durability (d)	10.0	20.0	0.0	20.0	20.0
mishap revenue (γ_o)	.8	.8	.8	.8	.8
neta (n)	-.45	-.45	-.45	-.45	-.45
automation mass (m_a)	1.0	1.0	1.0	1.0	1.0
durability mass (m_d)	.1	.1	.1	.1	.1
gamma 3	.5	.5	.5	.5	.5
alpha 1	5.37	5.37	1.00	5.37	5.37
gamma 1	.53	.53	.14	.53	.53
alpha 2	29.73	29.73	29.73	29.73	29.73
gamma 2	2.83	2.83	2.83	2.83	2.83
gamma 4	.29	.29	.00	.29	.29
cm	4.43	4.43	.20	4.43	4.43
automation cost (c_a)	24.64	24.64	24.64	24.64	24.64
durability cost (c_d)	.03	.03	.03	.03	.03
backup manhours (bh)	3.0	3.0	3.0	3.0	3.0
backup mass (bm)	12.0	12.0	12.0	12.0	12.0
max power ($\overline{p}$)	4.0	4.0	4.0	4.0	4.0
min power ($\underline{p}$)	0.0	0.0	0.0	0.0	0.0
max manhours ($\overline{h}$)	6.0	6.0	6.0	6.0	6.0
min manhours ($\underline{h}$)	0.0	0.0	0.0	0.0	0.0
initial cost (c_o)	49.58	99.20	2.3	12.92	49.88
group cost (c_g)	7.5	7.5	7.5	7.5	7.5
slip cost (c_s)	9.0	9.0	9.0	9.0	9.0
in-flight cost (c_f)	5.0	5.0	5.0	5.0	5.0
max operating periods (o)	1.0	1.0	1.0	1.0	1.0
min development time (θ)	1.0	1.0	1.0	1.0	1.0
probability of slip	.33	.33	.33	.33	.33
probability of mishap (σ)	.33	.25	1.00	.25	.25
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	2.0	6.0	0.0	3.0	4.0
pi foot ($\underline{\pi}$)	37.0	37.0	37.0	37.0	37.0
max mass ($\overline{m}$)	8.0	8.0	9.0	8.0	8.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 6	A*	B	C	D	E
automation (a)	4.0	4.0	1.5	4.0	0.0
durability (d)	4.0	8.0	4.0	16.0	0.0
mishap revenue (γ_o)	.9	.9	.9	.9	.9
neta (n)	-.5	-.5	-.5	-.5	-.5
automation mass (m_a)	2.0	2.0	2.0	2.0	2.0
durability mass (m_d)	.25	.25	.25	.25	.25
gamma 3	.6	.6	.6	.6	.6
alpha 1	5.93	5.93	5.93	5.93	1.00
gamma 1	.37	.37	.37	.37	.14
alpha 2	10.91	10.91	10.91	10.91	10.91
gamma 2	.82	.82	.82	.82	.82
gamma 4	.92	.92	.92	.92	.00
cm	13.30	13.30	13.30	13.30	.20
automation cost (c_a)	9.07	9.0	9.07	9.07	9.07
durability cost (c_d)	.16	.16	.16	.16	.16
backup manhours (bh)	3.0	3.0	3.0	3.0	3.0
backup mass (bm)	11.0	11.0	11.0	11.0	11.0
max power ($\overline{p}$)	5.0	5.0	5.0	5.0	5.0
min power ($\underline{p}$)	2.0	2.0	2.0	2.0	2.0
max manhours ($\overline{h}$)	6.0	6.0	6.0	6.0	6.0
min manhours ($\underline{h}$)	2.0	2.0	2.0	2.0	2.0
initial cost (c_o)	36.92	37.56	14.25	38.84	2.32
group cost (c_g)	9.0	9.0	9.0	9.0	9.0
slip cost (c_s)	12.0	12.0	12.0	12.0	12.0
in-flight cost (c_f)	5.0	5.0	5.0	5.0	5.0
max operating periods (o)	1.0	1.0	1.0	1.0	1.0
min development time (θ)	2.0	2.0	2.0	2.0	2.0
probability of slip	.25	.25	.25	.25	.25
probability of mishap (σ)	.45	.33	.45	.25	1.0
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	9.0	10.0	4.0	12.0	0.0
pi foot ($\underline{\pi}$)	42.0	42.0	42.0	42.0	42.0
max mass ($\overline{m}$)	8.0	8.0	8.0	8.0	9.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

Subject 7

	A	B*	C	D	E
automation (a)	1.0	1.0	1.0	1.0	1.0
durability (d)	50.0	0.0	10.0	50.0	10.0
mishap revenue (γ_o)	.75	.75	.75	.85	.85
neta (n)	-.5	-.5	-.5	-.5	-.5
automation mass (m_a)	0.0	0.0	0.0	0.0	0.0
durability mass (m_d)	.1	.1	.1	.1	.1
gamma 3	.6	.6	.6	.6	.6
alpha 1	2.75	2.75	2.75	2.60	2.60
gamma 1	.25	.25	.25	.15	.15
alpha 2	3.70	3.70	3.70	3.60	3.60
gamma 2	.5	.5	.5	.3	.3
gamma 4	.00	.00	.00	.00	.00
cm	.20	.20	.20	.20	.20
automation cost (c_a)	2.07	2.07	2.07	2.07	2.07
durability cost (c_d)	.01	.01	.01	.01	.01
backup manhours (bh)	2.0	2.0	2.0	2.0	2.0
backup mass (bm)	4.0	4.0	4.0	4.0	4.0
max power ($\overline{p}$)	4.0	4.0	4.0	4.0	4.0
min power ($\underline{p}$)	0.0	0.0	0.0	0.0	0.0
max manhours ($\overline{h}$)	4.0	4.0	4.0	4.0	4.0
min manhours ($\underline{h}$)	0.0	0.0	0.0	0.0	0.0
initial cost (c_o)	2.57	2.07	2.17	2.57	2.17
group cost (c_g)	5.0	5.0	5.0	5.0	5.0
slip cost (c_s)	10.0	10.0	10.0	10.0	10.0
in-flight cost (c_f)	5.0	5.0	5.0	5.0	5.0
max operating periods (o)	1.0	1.0	1.0	1.0	1.0
min development time (θ)	1.0	1.0	1.0	1.0	1.0
probability of slip	.1	.1	.1	.1	.1
probability of mishap (σ)	.15	1.0	.30	.15	.30
initial mass (m_o)	0.0	0.0	0.0	0.0	0.0
primary mass	5.0	0.0	1.0	5.0	1.0
pi foot ($\underline{\pi}$)	45.0	45.0	45.0	45.0	45.0
max mass ($\overline{m}$)	9.0	9.0	9.0	9.0	9.0
min mass ($\underline{m}$)	0.0	0.0	0.0	0.0	0.0

*Denotes optimal design

PROJECT LIST

		A	B	C	D	E
1.	PROJECT:	A	B	C	D	E
2.	PRIMARY MASS:	9	10	4	12	0
3.	PROBABILITY OF MISHAP:	0.45	0.33	0.45	0.25	1.00
4.	REQUIRED BACKUP TO RECOVER FROM MISHAP:					
	MANHOURS:	3	3	3	3	3
	OR					
	MASS:	11	11	11	11	11
5.	MAX OPERATING TIME (PERIODS):	1	1	1	1	1
6.	DEVELOPMENT TIME (PERIODS)	2	2	2	2	2
7.	INITIAL COST:	36.92	37.56	14.25	38.84	2.32
8.	DEVELOPMENT COST (PER PERIOD):	9.00	9.00	9.00	9.00	9.00
9.	PROBABILITY OF ONE PERIOD DELAY	0.25	0.25	0.25	0.25	0.25
10.	SPEED-UP COST:	12.00	12.00	12.00	12.00	12.00
11.	IN-FLIGHT GROUND COST (PER PERIOD)	5.00	5.00	5.00	5.00	5.00

MASS REVENUE SHEET

	PROJECTS: A,B,C,D		PROJECT E	
MASS UNIT	ADDITIONAL REVENUE	TOTAL REVENUE	ADDITIONAL REVENUE	TOTAL
1	12.38	12.38	0.20	0.20
2	10.54	22.92	0.20	0.40
3	8.70	31.62	0.20	0.60
4	6.86	38.48	0.20	0.80
5	5.02	43.50	0.20	1.00
6	3.18	46.68	0.20	1.20
7	1.34	48.02	0.20	1.40
8	0.00	48.02	0.20	1.60
9	0.00	48.02	0.20	1.80
10	0.00	48.02	0.00	1.80
11	0.00	48.02	0.00	1.80
12	0.00	48.02	0.00	1.80
13	0.00	48.02	0.00	1.80
14	0.00	48.02	0.00	1.80
15	0.00	48.02	0.00	1.80
16	0.00	48.02	0.00	1.80
17	0.00	48.02	0.00	1.80
18	0.00	48.02	0.00	1.80
19	0.00	48.02	0.00	1.80
20	0.00	48.02	0.00	1.80

Subject 6

Project A

NORMAL REVENUE TABLE

POWER

MANHOURS

	0		2		3		4		5
0	0.00	52.38	52.38	4.08	56.46	3.34	59.80	2.60	62.40
	84.59		42.59		42.59		42.59		42.59
2	84.59	10.38	94.97	4.08	99.05	3.34	102.39	2.60	104.99
	15.65		15.65		15.65		15.65		15.65
3	100.24	10.38	110.62	4.08	114.70	3.34	118.04	2.60	120.64
	11.88		11.88		11.88		11.88		11.88
4	112.12	10.38	122.50	4.08	126.58	3.34	129.92	2.60	132.52
	8.11		8.11		8.11		8.11		8.11
5	120.23	10.38	130.61	4.08	134.69	3.34	138.03	2.60	140.63
	4.34		4.34		4.34		4.34		4.34
6	124.57	10.38	134.95	4.08	139.03	3.34	142.37	2.60	144.97

MISHAP REVENUE TABLE

POWER

MANHOURS

	0		2		3		4		5
0	0.00	51.34	51.34	3.67	55.01	3.01	58.02	2.34	60.36
	80.33		38.33		38.33		38.33		38.33
2	80.33	9.34	89.68	3.67	93.35	3.01	96.35	2.34	98.69
	14.08		14.08		14.08		14.08		14.08
3	94.42	9.34	103.76	3.67	107.43	3.01	110.44	2.34	112.78
	10.69		10.69		10.69		10.69		10.69
4	105.10	9.34	114.45	3.67	118.12	3.01	121.12	2.34	123.46
	7.30		7.30		7.30		7.30		7.30
5	112.40	9.34	121.75	3.67	125.42	3.01	128.42	2.34	130.76
	3.91		3.91		3.91		3.91		3.91
6	116.31	9.34	125.65	3.67	129.33	3.01	132.33	2.34	134.67

Subject 6

Project B

NORMAL REVENUE TABLE

POWER

MANHOURS

	0		2		3		4		5
0	0.00	52.38	52.38	4.08	56.46	3.34	59.80	2.60	62.40
	84.59		42.59		42.59		42.59		42.59
2	84.59	10.38	94.97	4.08	99.05	3.34	102.39	2.60	104.99
	15.65		15.65		15.65		15.65		15.65
3	100.24	10.38	110.62	4.08	114.70	3.34	118.04	2.60	120.64
	11.88		11.88		11.88		11.88		11.88
4	112.12	10.38	122.50	4.08	126.58	3.34	129.92	2.60	132.52
	8.11		8.11		8.11		8.11		8.11
5	120.23	10.38	130.61	4.08	134.69	3.34	138.03	2.60	140.63
	4.34		4.34		4.34		4.34		4.34
6	124.57	10.38	134.95	4.08	139.03	3.34	142.37	2.60	144.97

MISHAP REVENUE TABLE

POWER

MANHOURS

	0		2		3		4		5
0	0.00	51.34	51.34	3.67	55.01	3.01	58.02	2.34	60.36
	80.33		38.33		38.33		38.33		38.33
2	80.33	9.34	89.68	3.67	93.35	3.01	96.35	2.34	98.69
	14.08		14.08		14.08		14.08		14.08
3	94.42	9.34	103.76	3.67	107.43	3.01	110.44	2.34	112.78
	10.69		10.69		10.69		10.69		10.69
4	105.10	9.34	114.45	3.67	118.12	3.01	121.12	2.34	123.46
	7.30		7.30		7.30		7.30		7.30
5	112.40	9.34	121.75	3.67	125.42	3.01	128.42	2.34	130.76
	3.91		3.91		3.91		3.91		3.91
6	116.31	9.34	125.65	3.67	129.33	3.01	132.33	2.34	134.67

Subject 6

Project C

NORMAL REVENUE TABLE

POWER

MANHOURS		0		2		3		4		5
M	0	0.00	52.38	52.38	4.08	56.46	3.34	59.80	2.60	62.40
A		65.65		23.65		23.65		23.65		23.65
N	2	65.65	10.38	76.03	4.08	80.11	3.34	83.45	2.60	86.05
H		8.69		8.69		8.69		8.69		8.69
O	3	74.33	10.38	84.71	4.08	88.79	3.34	92.13	2.60	94.73
U		6.59		6.59		6.59		6.59		6.59
R	4	80.93	10.38	91.31	4.08	95.39	3.34	98.73	2.60	101.33
S		4.50		4.50		4.50		4.50		4.50
	5	85.43	10.38	95.81	4.08	99.89	3.34	103.23	2.60	105.83
		2.41		2.41		2.41		2.41		2.41
	6	87.84	10.38	98.22	4.08	102.30	3.34	105.64	2.60	108.24

MISHAP REVENUE TABLE

POWER

MANHOURS		0		2		3		4		5
M	0	0.00	51.34	51.34	3.67	55.01	3.01	58.02	2.34	60.36
A		63.28		21.28		21.28		21.28		21.28
N	2	63.28	9.34	72.62	3.67	76.30	3.01	79.30	2.34	81.64
H		7.82		7.82		7.82		7.82		7.82
O	3	71.10	9.34	80.44	3.67	84.11	3.01	87.12	2.34	89.46
U		5.93		5.93		5.93		5.93		5.93
R	4	77.03	9.34	86.38	3.67	90.05	3.01	93.05	2.34	95.39
S		4.05		4.05		4.05		4.05		4.05
	5	81.09	9.34	90.43	3.67	94.10	3.01	97.11	2.34	99.45
		2.17		2.17		2.17		2.17		2.17
	6	83.25	9.34	92.60	3.67	96.27	3.01	99.27	2.34	101.61

Subject 6
Project D

NORMAL REVENUE TABLE

POWER

MANHOURS	0		2		3		4		5
0	0.00	52.38	52.38	4.08	56.46	3.34	59.80	2.60	62.40
	84.59		42.59		42.59		42.59		42.59
2	84.59	10.38	94.97	4.08	99.05	3.34	102.39	2.60	104.99
	15.65		15.65		15.65		15.65		15.65
3	100.24	10.38	110.62	4.08	114.70	3.34	118.04	2.60	120.64
	11.88		11.88		11.88		11.88		11.88
4	112.12	10.38	122.50	4.08	126.58	3.34	129.92	2.60	132.52
	8.11		8.11		8.11		8.11		8.11
5	120.23	10.38	130.61	4.08	134.69	3.34	138.03	2.60	140.63
	4.34		4.34		4.34		4.34		4.34
6	124.57	10.38	134.95	4.08	139.03	3.34	142.37	2.60	144.97

MISHAP REVENUE TABLE

POWER

MANHOURS	0		2		3		4		5
0	0.00	51.34	51.34	3.67	55.01	3.01	58.02	2.34	60.36
	80.33		38.33		38.33		38.33		38.33
2	80.33	9.34	89.68	3.67	93.35	3.01	96.35	2.34	98.09
	14.08		14.08		14.08		14.08		14.08
3	94.42	9.34	103.76	3.67	107.43	3.01	110.44	2.34	112.78
	10.69		10.69		10.69		10.69		10.69
4	105.10	9.34	114.45	3.67	118.12	3.01	121.12	2.34	123.46
	7.30		7.30		7.30		7.30		7.30
5	112.40	9.34	121.75	3.67	125.42	3.01	128.42	2.34	130.76
	3.91		3.91		3.91		3.91		3.91
6	116.31	9.34	125.65	3.67	129.33	3.01	132.33	2.34	134.07

Subject 6

Project E

NORMAL REVENUE TABLE

POWER

MANHOURS

	0		2		3		4		5
0	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.70
	0.00		0.00		0.00		0.00		0.00
2	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.76
	0.00		0.00		0.00		0.00		0.00
3	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.76
	0.00		0.00		0.00		0.00		0.00
4	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.76
	0.00		0.00		0.00		0.00		0.00
5	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.76
	0.00		0.00		0.00		0.00		0.00
6	42.00	1.44	43.44	0.30	43.74	0.02	43.76	0.00	43.76

MISHAP REVENUE TABLE

POWER

MANHOURS

-	0		2		3		4		5
0	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58
	0.00		0.00		0.00		0.00		0.00
2	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58
	0.00		0.00		0.00		0.00		0.00
3	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58
	0.00		0.00		0.00		0.00		0.00
4	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58
	0.00		0.00		0.00		0.00		0.00
5	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58
	0.00		0.00		0.00		0.00		0.00
6	42.00	1.30	43.30	0.27	43.57	0.02	43.58	0.00	43.58

APPENDIX B

NASA Subject Cover Letter

AGENDA

Today: Read the enclosed orientation.

Feb. 17 (Wednesday)

8:00 am	meet at Baxter Lecture Hall - Caltech (map enclosed)
8:05 am	instructions and meet with partner
9:00 am	begin experiment
12:00 noon	lunch
1:30 pm	continue experiment
	afternoon brief break
6:00 pm	try to finish by this time

Feb. 18 (Thursday)

8:00 am	meet at Baxter Lecture Hall - Caltech
8:30 am	overview of experiment (results)
10.00 am	debrief
11:00 am	future plans
12:00 noon	lunch
1:30 pm	future plans

ORIENTATION: NASA/JPL Personnel

In order for the upcoming exercise to be successful, we must rely upon you to orient yourself properly. The instructions enclosed are those that would be read by ordinary subjects. In addition, the exercise itself is ordinarily designed to focus on only part of the resource allocation puzzle. Since you are neither ordinary subjects nor are you interested in only a piece without seeing the whole puzzle, some special efforts on your part are required.

1. The situation is complex but the instructions are accurate and complete. Resist the temptation to become overwhelmed and frustrated. Study the material from the point of view of someone who has simply been asked to participate in an experiment about which he/she knows nothing. Forget that you really want to know about resource allocation policies and that you have no fundamental interest in an experiment. Confusion is expected and perhaps even necessary. Many questions such as how you get resources, how decisions are made, etc., will be answered when you arrive. Other questions regarding pricing policies will be discussed after the exercise.

2. You have been assigned a partner who can help you with some of the details. This partner is a Caltech student whom you will meet when you arrive. He has participated in the experiment before and is very knowledgeable about the instructional material enclosed. The partner can explain and answer technical questions but cannot advise you on decisions. All decisions are yours.

3. The income of your partner depends completely on the decisions you make. When the instructions refer to "payoffs" and "profits" these all go to your partner. Your success will be measured in terms of how much you can make for him.

4. Go about this task with an open mind. Don't try to second-guess the purpose and procedures. Here are some examples.

   i. What you will see as unnecessary complexity and redundancy in your particular experiment results from a need for instructional consistency across a variety of experiments. The instructions in the package are designed to accommodate a very wide range of experiments by making changes in tables only.

   ii. Don't rely on your knowledge of space station details to get you through this. You can be misled. The setting was not designed to capitalize on your special knowledge of space station.

   iii. Don't be confused by the use of money and the concept of payoffs. The procedures do not imply that scientists are motivated by cash payoffs or that a major portion of resource decisions necessarily have a monetary foundation. This method of motivation is fundamental to a long and successful record of experimental control. The payoffs give specific and controlled direction to the resource allocation conflicts.

5. Remember that the task is not simple and that all of the issues will be discussed after the experiment. Read the instructions today so you will have the opportunity for them to "soak in" and for further review. If you have any questions, call

Dave Porter	(818) 356-4156	Caltech office
	(818) 354-1286	JPL office
	(818) 798-0230	home

APPENDIX C

Instructions

D. INSTRUCTIONS

You are about to participate in an experiment designed to provide insights into certain features of decision processes. If you follow the instructions carefully and make good decisions you might earn a considerable amount of money. You will be paid in cash. In order to aid your understanding of the options you face and the decisions you might make we have described an imaginary situation. You will be managing projects which might be on a space station orbiting the earth. The descriptions of this situation are only to aid your understanding about how you make money. Beyond that purpose the realism or lack of it should be of no concern to you.

Each of you has been given a large folder. The contents of this folder are your private information. Do not give this information to any other participant. When you finish the experiment put everything back in your folder and return it to us. Take none of it home with you.

An overview of the experiment will be given with the aid of the calendar which you will find in your folder. The calendar is divided into periods and interims. At the beginning of each period a launch is made to transport projects to a space station. The interims are used for the development and selection of projects to go on the station and for the operation of projects on the station.

Your first task is to choose from among those projects described in your folder (PROJECTS FILE). After a project is chosen you must secure a position on the space station (APPLICATION). For this you will need transportation to the station and the resources (power and manhours) to operate your project while it is on the station. The value to you of operating a project is determined by the length of time you are operating on the station and the level at which your project operates (power and manhours used). Your costs include initial costs, development costs, ground costs, transportation costs and resource costs (power and manhours) incurred while on the station.

Development begins as soon as your project is started and can be influenced by chance. Similarly, the operations of the station and your own project can be influenced by chance. Such events affect you either directly through your income or indirectly by affecting your level of operation. The reliability of projects and station will be discussed in detail later.

You can have only one project operating on the station during a period. The station will operate many periods, so over time you might operate several different projects or even the same project many times.

We will first describe project operation revenues and costs. The descriptions will include project characteristics including reliability and the features of projects that are important for successfully operating on the station. Afterward we will discuss the appropriate accounting procedures.

The projects available to you are fully described by the PROJECT LIST and PROJECT RETURN FROM OPERATIONS TABLES. Each project is described by a series of characteristics. Each of these characteristics will be explained below. Please refer to your Project List Sheet.

The project primary mass is fixed for each project and is listed on line 2 of your Project List. It is important because it can affect the costs and the chance that your project will get to the station.

Project Returns from Operations: Associated with each project are Project Returns from Operations Tables that give the income generated each period that a project operates while on the station. Consider the table below, as an example of such a table. If the project is on the station and if 1 manhour and 2 units of power are used then the payment to you is 2330 for each period of operation. If manhours are increased by an hour to 2, then your payment is increased by 800 to 3130. The amounts in the parentheses in the table indicate the changes in the payoffs with one unit increases in the variables.

MANHOURS	0		1		2		3		4
0	0	(700)	700	(530)	1230	(340)	1570	(200)	1770
	(1100)		(1100)		(1100)		(1100)		(1100)
1	1100	(700)	1800	(530)	2330	(340)	2670	(200)	2870
	(800)		(800)		(800)		(800)		(800)
2	1900	(700)	2600	(530)	3130	(340)	3470	(200)	3670
	(400)		(400)		(400)		(400)		(400)
3	2300	(700)	3000	(530)	3530	(340)	3870	(200)	4070
	(100)		(100)		(100)		(100)		(100)
4	2400	(700)	3100	(530)	3630	(340)	3970	(200)	4170

You have a number of Project Return Tables. Initially you will use the Normal Project Return Table for the project selected. If a mishap occurs while the project is on the station then you will use the Mishap Return Table for the project selected. The probability of this occurrence is given in line ____. While a project is on the station a mishap can occur only for the first period it operates on the station.

Backup systems can be used to prevent mishaps and thus allow you to return to your initial table.

Backup systems can be used for no other purpose. The amount of backup necessary to use your initial Project Return Table should a mishap occur is given on line ____ of your Project List.

Additional mass beyond the primary mass is optional. The effect of additional mass is to increase the revenue that the project generates. The revenue that you accrue by using additional mass is received when your project is launched. However, it might be costly.

Maximum Operating Time: The number of periods that a project can operate to generate income is limited. The operating life of a project is located on line ___ of the Project List. Projects can exist on the station or the ground for any length of time without operating.

Ground Development Time: Once you start a project you will incur an initial cost which you can find on line _____ of your Project List. Normal development time from the project start is given on line ____. The development cost per period is given on line ____. One period delays can occur with the probability found on line ____ of your Project List. Your project can be delayed only once. You can speed up the development time of your project by one period by incurring the cost found on line ____ of your Project List. Should the project be idle on the ground when it is completed, the development costs continue to accrue each period. After you have started a project you can discontinue its development. However, you will still incur its initial cost and development cost for each period including the period in which it is "killed" (discontinued).

Ground Operations: While your project is on the station, in-flight ground costs will be incurred regardless of the level of operations. This cost can be found on line ____ of your Project List.

E. STATION CONTRACTS AND RESOURCES

Looking back to the calendar you will see that at interims 1.1, 1.2, 2.1, 2.2, etc. the resources available to be allocated at the station for the current period are checked and announced. The station's maximum capacity might be less than the posted amounts. For those on the station the priority system will be used to determine operations levels and individual operating levels will be announced. The unallocated rated capacities available for the next period will be announced.

As will be explained (and demonstrated) later the station's resources might be less than the rated capacities written on the board. If this occurs the resources will be allocated to priority 1 projects in proportion with initial allocations until the full allocations are achieved. The remaining resources will then be allocated to priority 2 projects in proportion with initial allocations, etc.

Applications are submitted by completing the application form found in your instructions folder. A standard form is shown on the chalkboard. Consider the following example:

Participant ________
Priority ________

APPLICATION

Application Number _______
Project Start Number _______

Launch Preference (Ordered) First Preference _______

Second Preference ______

Number of Periods on Station ____________

Mass: Priority 1 ________
Priority 2 ________
Backup: Priority 1 ________
Priority 2 ________
Total: Priority 1 ________
Priority 2 ________

CONSECUTIVE PERIODS ON STATION

		1st	2nd	3rd
Power:				
Operations:	Priority 1	________	________	________
	Priority 2	________	________	________
Manhours:				
	Priority 1	________	________	________
	Priority 2	________	________	________
Backup:	Priority 1	________	________	________
	Priority 2	________	________	________
Total:	Priority 1	________	________	________
	Priority 2	________	________	________

Participant _______
Application Number _______
Start Numb _______
Project _______

PROJECT ACCOUNTING SHEET

(a) primary mass ____ (b) additional mass ____ (c) backup mass ____

(d) development time ____ (c) operating time ____

(f) initial cost ____ (g) development cost ____ (h) speed-up cost ____

(i) in-flight ground cost ____ (j) starting period ____ (k) actual development time ____

(l) priods sped-up ____ (m) project completion period ____ (n) launch period ____

(o) period on station ____

(p)	period		____	____	____	____
(i)	allocated man-hours	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(ii)	allocated backup man-hours	(priority 1)	____	____	____	____
		(priority 1)	____	____	____	____
(iii)	allocated power	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(iv)	allocated additional mass	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(v)	actual man-hours	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(vi)	actual backup man-hours	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(vii)	actual power	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
(viii)	actual mass1	(priority 1)	____	____	____	____
		(priority 2)	____	____	____	____
1.	Revenue........ (using (v) and (viii))		____	____	____	____
2.	Initial Cost........ (from (f))		____	____	____	____
3.	Development Cost........ (from (g))		____	____	____	____
4.	Speed-up Cost........ ((h) x (f))		____	____	____	____
5.	Launch Costs........ (mass x ____)		____	____	____	____
6.	Man-hour Cost........ (man-hours)		____	____	____	____
7.	Power Costs........ (power x ____)		____	____	____	____
8.	In-flight Ground........ (from (i))		____	____	____	____
9.	Total Cost........ (2 + 3 + 4 + 5 + 6 + 7 + 8)		____	____	____	____
10.	Period Proci........ (1-9)		____	____	____	____

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